The interaction between the physical and mental loads associated with actual and simulated rugby league performance

Thesis submitted in accordance with the requirements of the University of Chester for the degree of Doctor of Philosophy

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September 2019

Abstract

The aim of the current thesis was to develop knowledge of the 'loads' associated with rugby league match-play, with a particular focus on the effects of altered mental loads before and during exercise indicative of a rugby league match. Chapter 3 examined the test-retest reliability of movement, physiological and perceptual measures during and after a novel rugby match simulation, where movement commands were more random than those typical of match simulations. The most reliable measure of external load during bouts of the simulation was relative distance (typical error [TE] and coefficient of variation [CV%] = 1.5-1.6 $m \cdot min^{-1}$ and 1.4-1.5%, respectively), with all other movement characteristics possessing a CV% <5%. The most reliable measure of internal load, neuromuscular function and perceptual measures were for %HRmax during bout 1 (TE and CV% = 1.4-1.7% and 1-4-2.1%, respectively), MVC before (TE and CV% = 10.8-14.8 N·m and 3.8-4.6%, respectively), and average RPE (TE and CV% = 0.5-0.8 AU and 3.6-5.5%, respectively). The conclusion of this chapter was that randomisation of the movements during simulated activity to better reflect intermittent team sports has no detrimental effect on its reliability. Studies can therefore confidently examine alterations in several perceptual, neuromuscular, physiological and movement load measures related to rugby activity using stochastic movements. Chapter 4 examined the responses to a simulated rugby league protocol that was designed to include more random commands, and therefore require greater vigilance, than traditional team sport simulation protocols. The randomised simulation (RDM) was matched for the number and types of activity performed every 5.45 min in a control trial (CON), but included no repeated cycles of activity. The RDM trial was more mentally demanding than CON (Effect size (ES) = 0.56; ±0.57). Self-paced mean sprint performance increased in RDM (22.5 ± 1.4 vs. 21.6 ± 1.6 $km \cdot h^{-1}$; ES = 0.50; ±0.45), which was accompanied by a higher RPE (14.3 ± 1.0 vs. 13.0 ± 1.4; ES = 0.87; ±0.54) and a greater number of errors in the Stroop Test (10.3 ± 2.5 vs. 9.3 ± 1.4 errors; ES = 0.65; ±0.67). MVC peak torque (CON = -48.4 ± 31.6 N·m, RDM = -39.6 ± 36.6 N·m) and voluntary activation (CON = -8.3 ± 4.8%, RDM = -6.0 ± 4.1%) was similarly reduced in both trials. Providing more random commands, requiring greater vigilance, can therefore alter performance and associated physiological, perceptual and cognitive responses to team sport simulations. Chapter 5 describes the subjective task load of elite rugby league match play using the NASA-TLX and examines their association with several contextual match factors, technical performance and external movement demands. Linear mixed modelling revealed that various combinations of contextual factors, technical performance and movement demands were associated with subjective task load (NASA-TLX). Greater number of tackles (η^2 = 0.18), errors (η^2 = 0.15) decelerations (η^2 = 0.12), increased sprint distance (η^2 = 0.13), losing matches (η^2 = 0.36) and increased perception of effort (η^2 = 0.27) lead to *most likely – very likely* increases in subjective total workload. These data provide a greater understanding of the internal load and their association with several contextual factors, technical performance and external movement demands during rugby league competition. The purpose of the final empirical chapter (Chapter 6) was to describe the effects of mental fatigue on simulated rugby league performance and to determine the effects of caffeine supplementation on simulated rugby league performance in the presence of mental fatigue. Completing a mentally demanding task increases participants' subjective rating of mental fatigue (pre = 29 ± 25 AU; post = 55 ± 20 AU) immediately before completing a simulation protocol. Impairments in sprint speed (ES = -0.18; ±0.19), sprint to contact speed (ES = -0.20; ±0.27), high-intensity running (ES = -0.30; ±0.24), high metabolic power > 20 $W \cdot kg^{-1}$ (ES =-0.50; ±0.51) and time to complete a passing accuracy task (ES = 0.54; ±0.63) were observed after mental fatigue. Caffeine supplementation (5 $mg \cdot kg^{-1}$) attenuated several adverse effects of mental fatigue before exercise replicating the demands of rugby league match play, with increased sprint speed (ES = 0.40; ±0.18), high-intensity running (ES = 0.50; ±0.53), high metabolic power > 20 $W \cdot kg^{-1}$ (ES = 0.33; ±0.38) and decreased time to complete a passing accuracy test (ES =-0.70; ±0.45). Mental fatigue affected internal loads, external loads and skill performance during simulated rugby league match play that appear to be centrally regulated by a decreased motivation and increased perception of effort. However, a single dose of caffeine taken 60 min before performance can attenuate several of these negative effects. In summary, the current thesis highlights several interactions between the physical and mental loads associated with actual and simulated rugby league performance.

Acknowledgements

This body of work could not have been completed without the advice and support -especially in times of adversity- from friends, family and colleagues, for which I will always be grateful.

Firstly I would like to acknowledge my supervisory team, Dr Jamie Highton and Prof. Craig Twist; your guidance and support has been second to none and to say I could not have done this without you is a huge understatement. I feel truly lucky to have worked with two supervisors that are great academics, but above all are two top blokes; thank you both for the opportunity to study for a PhD and belief in me. Jamie, as your first PhD student (as lead supervisor) I hope I haven't put you off doing it again (the students can only get better I'm sure), thank you for everything. A special mention must go to Prof. Craig Twist's carpentry skills and the help of Harry and Alfie Twist during the development and production of the rugby passing targets, much appreciated.

Secondly, to my fellow PhD students John Fernandes, Jonty Norris, Chelsea Oxendale and Nick Dobbin; you have all at some point helped me throughout the production of this thesis (by fuelling my coffee addiction if nothing else), for which I am sincerely grateful. I would also like to thank Prof. Ken Green and the staff in the Department of Sport and Exercise Sciences at the University of Chester for their support throughout my ~9 years of studies. Special thanks must go to my fellow Wathonion and Yorkshireman Dr Andy Scattergood for introducing me to the University of Chester, for which I will always be grateful.

To the players at St Helens RLFC and University of Chester rugby teams; thank you for your time and efforts throughout the production of this thesis. Special thanks must go to the staff at St Helens RLFC; Matt Daniels, Nathan Mill and Ollie Ersser who have helped me with data collection, without which lots of this work would not have been possible. I would also like to acknowledge the help of Daniel Kerr, Mark Bell and Kate Fielding during data collection.

Finally, thanks to Rotherham MBC for their financial support throughout my studies, with special thanks to Louise Pashley for her continued support.

My fiancé Nia, I cannot begin to describe the sacrifice and level of support that you have given to me throughout this PhD. Sorry for the endless late nights and evenings writing-up, but in testament to your kind, selfless nature you didn't complain once. I am (and will be) forever grateful.

Declaration

The material being presented for examination is my own work and has not been submitted for an award of this or another HEI except in minor particulars which are explicitly noted in the body of the thesis. Where research pertaining to the thesis was undertaken collaboratively, the nature and extent of my individual contribution has been made explicit.

Thomas Mullen

Signed: T. Mullen Date: 25/09/19

Publications

Mullen, T., Twist, C., & Highton, J. (2019). Stochastic ordering of simulated rugby match activity produces reliable movements and associated measures of subjective task load, cognitive and neuromuscular function. *Journal of sports sciences, 37*(21), 2506-2512. [doi.10.1080/02640414.2019.1646071]

Conference Proceedings

Mullen, T., Twist, C., & Highton, J. (2017). The influence of stochastic movement patterns on external and internal load measures during simulated rugby league match play. Paper presented at the British Association of Sport and Exercise Sciences conference, Nottingham, UK.

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Chapter 1

Introduction

1.1 Monitoring 'Load' in Rugby League

Rugby league competition is known to place numerous demands on a player, which can be broadly classified as external (physical and technical) and internal (physiological and perceptual) loads (Halson, 2014; Impellizzeri, Marcora & Coutts, 2019). External loads describe the work completed by the athlete, whereas internal loads can be considered as the response to these external loads (Halson, 2014; Impellizzeri et al., 2019). Figure 1.1 is a theoretical model that demonstrates our current understanding (black text) of how external and internal loads are thought to interact, with specific examples relating to rugby league competition. That is, external loads impose a demand on a player (e.g. the distance that a player covers), which result in physiological and perceptual responses (e.g. increased heart rate or perceived effort; Impellizzeri et al., 2019; Waldron, Highton, Daniels & Twist, 2013).

Owing to the increased availability of sophisticated wearable micro-technology, sport scientists often examine the external load rather than the internal response to team sports performance (Cummins, Orr, O'Connor & West, 2013). This reporting of external loads is apparent within rugby league literature, with extensive research describing the movement demands associated with training (Gabbett, Jenkins & Abernethy, 2012; Gabbett & Jenkins, 2011; Twist, Highton, Daniels, Mill & Close, 2017; Weaving, Jones, Marshall, Till & Abt, 2017; Weaving et al., 2017a) and matches (Austin & Kelly, 2013; Black & Gabbett, 2014; Gabbett, 2012; Gabbett 2013a; Gabbett 2013b; Gabbett, Polley, Dwyer, Kearney & Corvo, 2014; Johnston, Gabbett & Jenkins, 2014; Kempton, Sirotic, Rampinini & Coutts, 2015; McLellan, Lovell & Gass, 2011b; Oxendale, Twist, Daniels & Highton, 2016; Sirotic, Coutts, Knowles & Catterick, 2009; Sirotic, Knowles, Catterick & Coutts, 2011; Sykes, Twist, Nicholas & Lamb, 2011; Twist et al., 2014; Twist et al., 2017; Waldron, Twist, Highton, Worsfold & Daniels, 2011; Waldron et al., 2013; Whitehead et al., 2018). Researchers and practitioners frequently document external loads in an attempt to monitor fatigue (Twist & Highton, 2013), optimise recovery (Oxendale et al., 2016), maximise the adaptations to, and specificity of, training (Gabbett et al., 2012; Lovell, Sirotic, Impellizzeri, & Coutts, 2013), and moderate injury risk (Hulin, Gabbett, Lawson, Caputi & Sampson, 2016; Thornton, Delaney, Duthie & Dascombe, 2017). Moreover, various loads relating to rugby league performance (e.g. number of collisions) are associated with symptoms of fatigue, comprising sensations of tiredness and impaired neuromuscular function that can persist for several days (Fletcher et al., 2016; Oxendale et al., 2016; Twist et al., 2012).

Internal loads have been explored in rugby league using heart rate (Waldron et al., 2011; Evans et al., 2015; Coutts, Reaburn & Abt, 2003), blood lactate (Coutts et al., 2003), and muscle glycogen (Bradley et al., 2016; Bradley et al., 2017). However, the most common measurement of internal load is session RPE (*s*RPE; Delaney, Duthie, Thornton & Pyne, 2018; Johnston et al., 2013; Lovell et al., 2013; Waldron et al., 2011; McLean, Coutts, Kelly, McGuigan & Cormack, 2010; Weaving et al., 2017a; Weaving et al., 2017b; Weaving, Marshall, Earle, Nevill & Abt, 2014). This method involves rating perceived exercise intensity using the Borg CR-10 scale (Foster et al., 2001) and is useful because it is non-invasive and affords a ‘global’ measure of internal load (Lovell et al., 2013). Within rugby league *s*RPE is often used to calculate training load (i.e. summated *s*RPE), whereby *s*RPE (0-10 AU) is multiplied by playing time (min; Lovell et al., 2013).

In Figure 1.1, physiological and perceptual measures are considered separate constructs of internal load, given that perceived loads can be affected by factors other than physical external loads. For example, distance covered high-speed running will increase both heart rate and perception of effort (Weaving et al., 2014; Delaney et al., 2018), whereas mental fatigue (i.e. a psychobiological state caused by prolonged periods of cognitively demanding activity) will increase perception of effort without any concomitant physiological response (Marcora, Staiano & Manning, 2009). It is notable that few studies have explored the effects of different external loads on perceived internal load (Weaving et al., 2014; Delaney et al., 2018), nor have any studies considered the role that non-physical demands have on perceived load in rugby league.

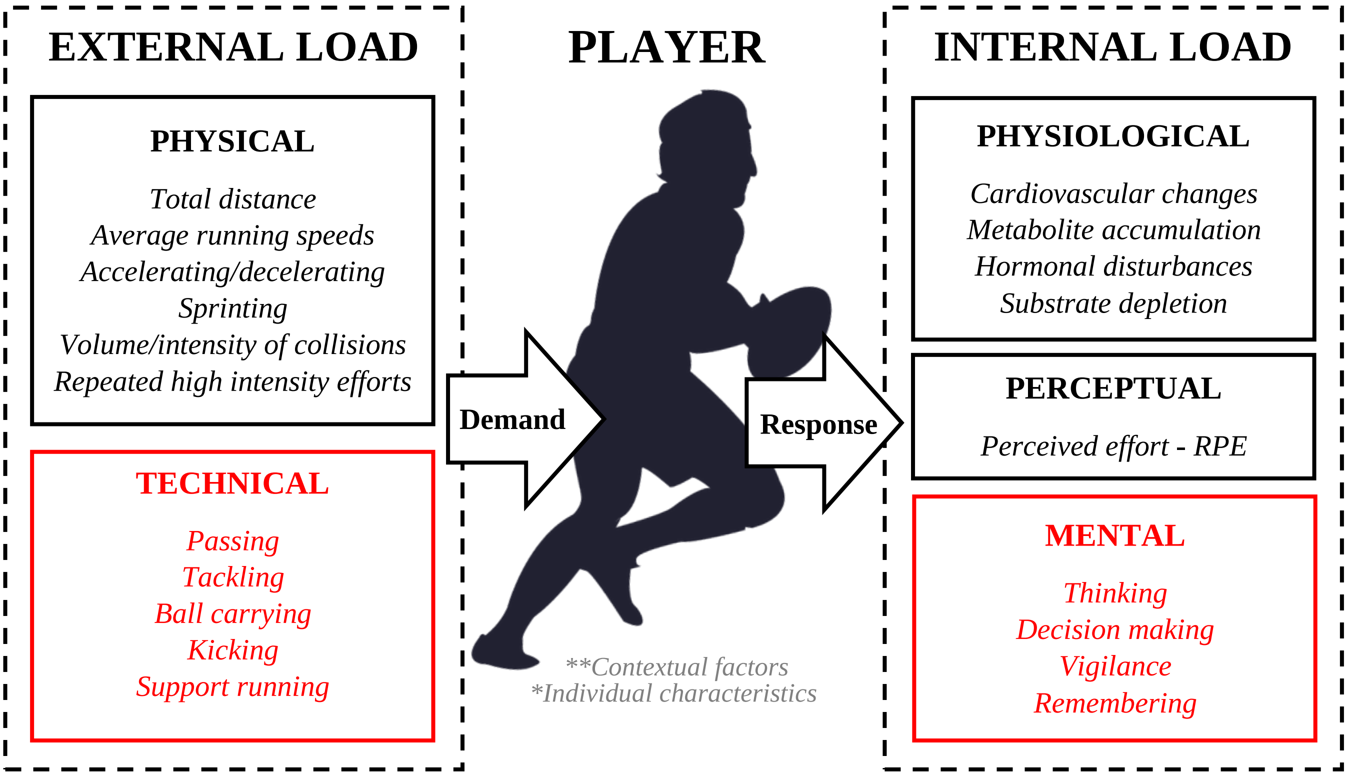

Figure 1.1 Proposed theoretical model of the external and internal loads associated with rugby league competition (*adapted from* Impellizzeri, Marcora & Coutts, 2019), modified to include technical and mental loads. **e.g. playing experience, psychological status, genetic factors, health, nutrition; **e.g. match location, match outcome, opposition quality.* Red ink denotes where the current thesis will develop the current understanding of load monitoring in rugby league.

1.2 Mental Loads during Rugby League Performance

The mental load associated with team sport performance, and its contribution to total load, is poorly understood (Halson, 2014). Mental loads are defined as the amount of perceptual or mental activity associated with thinking, deciding, calculating, remembering, looking and searching (Hart & Staveland, 1988). Altered mental loads during exercise tasks have been shown to alter vigilance requirements, attentional focus and perceived exertion (Greig, Marchant, Lovell, Clough & McNaughton, 2007), which might have implications for competitive performance. It is likely that the technical requirements of rugby league competition (e.g. decision making, skill execution) impose a mental load on rugby league players; however, the potential for technical demands to impose a mental load on players is currently unknown. As such, monitoring these loads and exploring their implications for total load and performance is worthy of investigation. An appraisal of the current model of load monitoring is suggested in Figure 1.1 highlighted in red text, whereby technical demands and subsequent mental loads associated with rugby league are incorporated in the model.

Differential RPE (*d*RPE) was recently used to quantify and discriminate the internal loads associated with rugby union training, including individual session ratings for breathlessness, upper/lower body muscle exertion and cognitive demands (McLaren, Smith, Spears & Weston, 2017). Within this study, cognitive and technical demands were considered within the same construct (*d*RPE-T; technical and cognitive), suggesting that the cognitive loads imposed on a player are synonymous with the technical requirements of performance (McLaren et al., 2017). McLaren et al. (2017) demonstrated that *d*RPE-T was able to discriminate between the load experienced in technical training sessions (e.g. skill training) in rugby union players, suggesting that cognitive load should be incorporated into rugby load monitoring.

To date, limited research exists describing the mental loads associated with the technical demands of rugby league performance. McLellan, Lovell and Gass (2011c) reported an increase in salivary cortisol after rugby league match play, which was ascribed to the psychological (anxiety and stress) and physical (high intensity running with collisions) loads imposed on the players; however, the extent to which each load affected cortisol response was not clear. Mashiko, Umeda, Nakaji & Sugawara (2004) reported that rugby union competition also culminates in subjective symptoms of mental fatigue (i.e. altered profile of mood state) after a match; again, the extent to which different match actions were related to these perceived mental load was not explored. Finally, Kempton et al. (2013) reported factors that are likely to impose a mental load (e.g. number of skill involvements) were correlated with physical loads (e.g. total distance covered). However, the mental 'load' present during rugby union training (McLaren et al., 2017) and matches (Mashiko et al., 2004), have limited application to the specific demands associated with rugby league competition. Indeed, the technical, tactical and physical demands differ between rugby codes (league and union; e.g. lineouts are considered a technical skill in rugby union, whilst rugby league does not have 'lineouts') that will likely result in varied physical and mental loads. Taken together, these studies suggest that rugby players are subject to considerable mental, as well as physical loads (Mashiko et al., 2004; McLellan et al., 2011c). However, the implications of each load and the extent to which they are related has not been explored. Therefore, research is warranted to better understand the mental loads associated with rugby league match-play and explore how external loads, technical demands and contextual factors might inform a player's subjective mental load.

The large match-to-match variations in movement demands (e.g. ~15% for high-intensity running; Kempton, Sirotic & Coutts, 2014) and the intermittent nature of match-play make it difficult to establish meaningful changes in performance and obtain physiological and perceptual data during matches (Coutts et al., 2003). Subsequently, simulation protocols have been designed to replicate several movement and physiological demands of team sport competition in controlled environments, to allow meaningful changes in performance to be detected (Nicholas, Nuttall & Williams, 2000; Scanlan, Dascombe & Reaburn, 2014; Sykes, Nicholas, Lamb & Twist, 2013; Waldron, Highton & Twist, 2013). These simulations offer a reliable research model to manipulate and determine the effects of, for example, manipulated mental loads. It is also noteworthy that current simulations of rugby league match-play (rugby league match simulation protocols; RLMSP) are predominantly derived from the documented external (movement) loads (Sykes, Twist, Hall, Nicholas & Lamb, 2009; Waldron et al., 2011), with little regard for the mental demands associated with match performance (Sykes et al., 2013; Waldron et al., 2013a). As such, the mental load that current rugby league simulations place on participants should be investigated, along with the extent to which this mental load can affect the use of simulation protocols.

1.3 Mental Fatigue and Rugby League Performance

It is well documented that exposing individuals to prolonged and demanding mental loads can lead to a psychobiological state termed mental fatigue (Van Cutsem et al., 2017). This mental fatigue is characterised by increased subjective mental fatigue and decreased motivation (Van Cutsem et al., 2017), which can have adverse effects on subsequent cognitive, skilled and physical performance (Boksem, Meijman & Lorist, 2005; Marcora et al., 2009; Smith, Marcora & Coutts, 2015). Indeed, prolonged periods (30-90 min) of mental loads (response inhibition tasks) will impair subsequent self-paced endurance (Brownsberger, Edwards, Crowther & Cottrell, 2013; Pageaux, Lepers, Dietz & Marcora, 2014), constant-load endurance (Marcora et al., 2009; Pageaux, Marcora & Lepers, 2013) and intermittent running performance (Smith et al., 2015). Whilst the effects of mental fatigue on subsequent endurance or intermittent exercise are known; fewer studies have explored the effects of mental fatigue on more complex exercise modes including physical, skill and cognitive demands that are characteristic of team sports. In soccer, mental fatigue impaired endurance (YoYo intermittent recovery test) and technical (Loughborough soccer passing test) performance (Smith et al., 2016). Similarly, during soccer small-sided games (SSGs), mental fatigue increased the time spent at low intensities (e.g. walking and standing) and decreased defensive and offensive involvements (e.g. tackles, passes and pass accuracy; Badin, Smith, Conte & Coutts, 2016). Recent evidence suggests that elite team sports athletes experience acute and chronic mental fatigue in their daily life which is perceived by coaches and players to have negative effects on subsequent training and competition (Russell, Jenkins, Rynne, Halson & Kelly, 2019). To date, no studies have directly explored the effect of mental fatigue in other team sports such as rugby league. Therefore, research is warranted to establish the effects of mental fatigue on the movement, technical, physiological and perceptual loads associated with rugby league competition. Given the potential for mental fatigue to impair subsequent rugby related performance, interventions which abate these effects are also warranted.

1.4 Summary

Our current understanding of the loads imposed on rugby league players are fundamentally derived from a one-dimensional model of load monitoring (Figure 1.1), whereby external demands produce internal responses (Halson, 2014; Impellizzeri et al., 2019). These internal and external loads were originally described to provide clarity when monitoring training loads and their physiological response in soccer (Impellizzeri, Rampinini, Coutts, Sassi & Marcora, 2004). Consequently this theoretical model fails to incorporate several pertinent external (e.g. technical loads) and internal loads (e.g. mental loads) associated with team sport competition. The specific mental loads during rugby league performance are yet to be considered, which is interesting given the well documented effects of altered mental loads on exercise performance (Greig et al., 2007; Van Cutsem et al., 2017; Warm, Parasuraman & Matthews, 2008). Indeed, the available literature suggests that exposing players to a prolonged mental load before exercise would impair subsequent components of rugby league match-play, including cognitive, skilled and physical performance (Smith et al., 2015; Marcora et al., 2009; Boksem et al., 2005). However, the precise manner by which altered mental loads affect rugby league performance is currently unknown and warrants further investigation. Finally, given that altered mental loads potentially impair subsequent rugby related performance, interventions that ameliorate these effects should also be investigated.

1.5 Organisation of the Thesis

Chapter 2 of the thesis is a review of literature regarding the 'load' associated with actual and simulated rugby league competition, with specific reference to mental load and mental fatigue. Thereafter, four chapters present empirical data on the reliability of a modified (stochastic) rugby league match simulation (Chapter 3), the effect of altered (stochastic) order of activity during simulated rugby league performance on pertinent internal (physiological and perceptual) and external (movement) load measures (Chapter 4), the mental demands associated with rugby league competition (Chapter 5) and the effects of mental fatigue on simulated rugby league performance with-and-without caffeine supplementation (Chapter 6). Finally, Chapter 7 presents conclusions on the potential effects of altered mental loads before and during exercise relating to rugby league competition, providing practical applications and directions for future research.

Chapter 2

Review of Literature

2.1 Introduction

The purpose of this Chapter was threefold: firstly, to review the literature describing the internal and external loads during rugby league matches and simulation protocols; secondly, to review the potential effects of altered mental loads on team sport performance; and finally, to appraise the efficacy of acute caffeine supplementation on team sport performance, with a particular focus on mechanisms that might limit mental fatigue.

2.2 Rugby League Match Load

Rugby league is a contact team sport, characterised by periods of high intensity activity (sprinting, running and tackling) interspersed with low intensity recovery (jogging, walking and standing). Matches are competed between two teams of 13 players, taking place over two 40-minute halves (excluding stoppages/injury time) separated by ~ 10 min rest interval at half-time (Gabbett, 2005). Players are classified into one of nine positional groups: prop, hooker, second rower, loose forward, scrum halve, stand-off, centre, winger, and fullback. These positions can be sub-grouped into hit-up forwards (prop and second row), adjustables (half back, stand-off, hooker and loose forward), and outside backs (winger, full back, and centre), or more broadly into forwards (prop, second rower and loose forward) and backs (hooker, scrum halve, stand-off, centre, winger and fullback). Distinct behavioural differences exist within these positional roles; for example, forwards will primarily carry the ball forward into collisions to gain positive ground, whereas the outside backs and adjustables travel greater distances, run more into open spaces and support offensive plays (Twist et al., 2014).

Rugby league competition is known to place numerous demands – or 'loads' - on a player, which can be broadly classified as external (physical and technical) and internal (physiological and perceptual) loads (Halson, 2014; Impellizzeri et al., 2019). In brief, the external loads include those physical demands imposed on a player (e.g. number of sprints and tackles), whereas internal loads can be considered as the response to given external loads (e.g. changes in heart rate or perceived exertion). It has become common practice for researchers and practitioners to document these loads, in an attempt to monitor fatigue, optimise recovery, maximise the adaptations to, and specificity of training, and moderate injury risk. The following sections discuss the relevant literature describing rugby league match load.

2.2.1 External Load (Physical)

Advancements in athlete tracking technology, namely global positioning systems (GPS) with inbuilt micro-sensor technology (e.g. accelerometers, magnetometers and gyroscopes), has permitted the detailed quantification of the external loads (physical demands) imposed on players during rugby league matches (Black & Gabbett, 2014; Evans et al., 2015; Gabbett et al., 2014; Gabbett, 2013a; Gabbett, 2013b; Hausler, Halaki & Orr, 2016; Johnston et al., 2014; Oxendale et al., 2016; Sykes et al., 2009; Twist et al., 2014; Twist et al., 2017; Waldron et al., 2011). In brief, the total distance covered by players will vary between 3000 – 8000 m, depending on playing position. Outside backs cover greater distances (7000-8000 m) than adjutsables (6000-7000 m) and hit up forwards (3000-6000 m; Twist et al., 2014; Waldron et al., 2011; Oxendale et al., 2016; Sykes et al., 2009; Gabbett et al., 2012; Gabbett et al., 2013). Playing time for hit up forwards (~ 50 min) is less than adjustables (~ 70 min) and outside backs (~ 80 min). Although total distance and playing times are lower in hit up forwards, relative distances ($m \cdot min^{-1}$) are similar between positional groups (~ 95 $m \cdot min^{-1}$, pooled data). Relative distances vary depending on playing standard, match outcome and phase of play (Johnston et al., 2014). Higher match intensities are reported during elite (~100 $m \cdot min^{-1}$) *cf.*

semi-elite (93 m·min^{-1}; Gabbett, 2013b), winning (~100 m·min^{-1}) *cf.* losing (~85 m·min^{-1}; Black & Gabbett, 2014), and during defence (~109 m·min^{-1}) *cf.* attack (~82 m·min^{-1}; Gabbett et al., 2014).

Given the intermittent nature of rugby league match play, the total distance covered by players comprises varying amounts of time spent in low intensity activity (~0.1–6.9 km·h^{-1}), moderate intensity running (~7.0–13.9 km·h^{-1}), high intensity running (~14.0–21.0 km·h^{-1}), and very high intensity running or sprinting (>21 km·h^{-1}; Waldron et al., 2011; Sykes et al., 2011). Importantly, players are required to perform high intensity efforts at critical parts of a match (Austin, Gabbett & Jenkins, 2011; Gabbett et al., 2013). Outside backs will cover more distance in high intensity running (>18 km·h^{-1}; ~450 m) compared to adjustables (~320 m) and hit up forwards (~250 m; Gabbett, 2013a). Decrements in high speed running have been reported in progressive quartiles of a rugby league match, indicative of match-related fatigue (Waldron & Highton, 2014). Players typically demonstrate 20-30% reductions in high speed running from the first quartile to the final quartile of a match (Waldron et al., 2013; Sykes et al., 2011). The interchange rule in rugby league, permitting up to 8 interchanges throughout a match, results in several players (generally forwards) performing two briefer bouts (~20 min; Waldron et al., 2013). These shorter bouts are generally performed at higher intensities, with greater relative distance high speed running (>14 km·h^{-1}) compared to whole match players (Waldron et al., 2013). These interchange players demonstrate similar match related fatigue with progressive decrements in high speed running from the first to the third quartile (~20 – 30%; Waldron et al., 2013) before increasing in the final quartile, indicative of an end-spurt (Waldron & Highton, 2014).

Players are also frequently involved in collisions (tackle or being tackled) that are largely considered the most demanding aspect of rugby league match-play (Weaving et al., 2019), with forwards (~40 – 50 per match) involved in more collisions than backs (~25 – 30 per match;

Evans et al., 2015; Gabbett et al., 2011; Gabbett et al., 2012; Oxendale et al., 2016; Twist et al., 2012). Whilst hit up forwards cover less distance in high speed running, they are involved in more collisions per minute of playing time (~1 per min), compared to adjustables (~0.6 per min) and outside backs (~0.3 per min; Gabbett et al., 2012; Twist et al., 2012).

During both offensive and defensive collisions, players will wrestle with the opposition to gain a 'dominant' position (Gabbett, 2005). These wrestling efforts impose further physical load, with reduced running activity observed when wrestling is included in small-sided games (Gabbett et al., 2012; Johnston, Gabbett, Seibold & Jenkins, 2014; Johnston, Gabbett & Jenkins, 2015). Positional differences are also evident in sprint frequency, with hit up forwards completing more sprints (~39) than outside backs (~35) and adjustables (~31; Gabbett, 2012). Moreover, the total number of sprints appear to be important to match outcome, with more successful teams (top four teams in the league) performing more sprint efforts (~49) compared to less successful sides (~33; bottom four teams in the league; Gabbett, 2014).

Repeated high intensity efforts (RHIE) have been used to quantify the most demanding periods of match play, defined as three or more maximal acceleration efforts (> 2.79 $m \cdot s^2$), very-high speed sprint efforts (>18 $km \cdot h^{-1}$), and/or tackle efforts with less than 21 s between efforts (Gabbett et al., 2012; Hausler et al., 2016). Unclear differences in the absolute number of RHIE bouts over the entire match are reported between playing positions (~8.5 bouts/match). However, when reported relative to playing time, forwards perform more RHIE bouts (one every 5 min) compared to adjustables (one every 8 min) and outside backs (one every 9 min; Gabbett et al., 2012). Research has found that RHIE bouts frequently occur in professional rugby league match-play at critical times within the match (e.g. immediately before points scored; Austin et al., 2011).

Technology companies have developed novel measures of external load using the micro-sensor technology within GPS units (accelerometer, gyroscope and magnetometer). The most commonly reported GPS derived metric is PlayerLoad™, measured using the inbuilt tri-axial accelerometer (Roe, Halkier, Beggs, Till & Jones, 2016; Gabbett, 2015; Weaving, Jones, Marshall, Till & Abt, 2017). PlayerLoad™ is calculated as the instantaneous rate of change of acceleration in three planes of motion (medio-lateral, longitudinal and anterior-posterior), producing an arbitrary value for total acceleration load. Average PlayerLoad™ throughout a competitive rugby league match is ~630 AU (Gabbett, 2015). Within this study, positional differences were apparent, with adjustables accumulating more PlayerLoad™ throughout a match (~680 AU), compared to hit up forwards (~540 AU) and outside backs (~606 AU; Gabbett, 2015).

2.2.2 External Load (Technical)

Rugby players are required to perform a variety of technical skills throughout a match. Importantly, the ability of a player to both deal with the physical demands and effectively execute these technical skills will largely determine successful performance (i.e. scoring more tries and winning matches; Gabbett, 2005). Matches involve a significant technical load, with players involved -on average- in a carry (travelling whilst in possession of the ball) every ~6 min, a support run (offensive movement close to a ball carrier with intention of receiving the ball) every ~4 min, touching the ball every ~2 min, play-the-ball (play the ball backwards following being tackled) every ~8 min and involved in a collision (physical contact with an opposition player) every ~4 min (Sirotic et al., 2009). Forwards will perform one play the ball, ball carry, support run and touch the ball every ~4 min, compared to backs who will perform one play the ball, ball carry, support run and touch the ball every ~11, 9, 4 and 6 min, respectively (Sirotic et al., 2011). Not surprisingly, Gabbett and colleagues have documented that elite players will possess superior tackling technique, draw and pass proficiency, and greater anticipation skills then amateur and academy players (Gabbett, Jenkins & Abernethy, 2011a; Gabbett & Ryan, 2009; Gabbett, Kelly & Sheppard, 2008; Gabbett, Wake & Abernethy, 2011). Match related fatigue also appears to reduce skill and technical performance after the peak 5 min period (most distance covered >14.4 $km{\cdot}h^{-1}$ within 5 min rolling average) of elite rugby league match-play (Kempton et al., 2013).

2.2.3 Internal Load (Physiological)

Internal load is described as the physiological stress (e.g. cardiovascular demand) imposed on a player resulting from an external load (e.g. running demands; Halson, 2014). Research quantifying the physiological load of rugby league has most often described changes in heart rate ($beats{\cdot}min^{-1}$) and blood lactate concentrations ($m{\cdot}mol{\cdot}L^{-1}$; Waldron et al., 2011; Evans et al., 2015; Coutts et al., 2003).

Elite rugby league match-play results in average heart rates ~84% HR_{max} across all playing positions (Waldron et al., 2011), with most time (~34 – 43%) spent at 80 – 90% HR_{max} across all playing positions (Evans et al., 2015). Summated heart rate, calculated according to Edwards (1993) training impulse (TRIMP; i.e. duration in heart rate zone x heart rate zone), demonstrated hit up forwards had lower TRIMP scores compared to adjustables and outside backs (~200, ~270 and ~300 AU, respectively; Waldron et al., 2011). These positional differences in summated heart rate are likely due to differences in playing times between positional groups (Waldron et al., 2011).

Blood lactate concentrations of ~8 $m{\cdot}mol{\cdot}L^{-1}$ and ~6 $m{\cdot}mol{\cdot}L^{-1}$ highlight a significant anaerobic demand associated with the first and second half of amateur rugby league match play, respectively (Coutts et al., 2003). However, quantifying internal load using blood lactate concentrations can be problematic, given the large individual variability and effect of immediately preceding exercise on lactate concentrations (Coutts et al., 2003). In addition, logistical difficulties and the invasive methods of determining blood lactate concentrations (i.e. capillary blood sampling) have subsequently limited the use after elite rugby league matches. It should also be noted that blood lactate concentrations might not reflect lactate in the muscle, owing to different rates of release (from muscle) and clearance (from blood), that is restricted during high intensity exercise (Krustrup et al., 2016).

Muscle biopsies taken immediately before and after competitive rugby league match-play have provided further insight into metabolism associated with rugby league (Bradley et al., 2016). Bradley et al. (2016) reported a ~40% decline in muscle glycogen immediately after a match, which is similar to observations in other team sports (Krustrup et al., 2006). This depletion of glycogen is likely due to high rates of aerobic and anaerobic glycolysis, which are associated with exercising at intensities greater than 70% $\dot{V}O_{2max}$ (van Loon et al., 2001). Bradley et al. (2016) also observed increases in plasma non-esterified fatty acids and glycerol after a match, indicating an increase in lipolysis to support metabolism. However, the extent to which fat oxidation supports ATP resynthesis in a rugby league match is not yet known.

Micro-technology has been used to predict the metabolic cost of team sport exercise, based on an estimated energy cost of constant-speed running on a flat surface, and the assumption that accelerating on a flat surface is metabolically equivalent to incline running at a constant speed (Di Prampero et al., 2005; Osgnach, Poser, Bernardini, Rinaldo & Di Prampero, 2010). Kempton et al. (2015) applied this novel measure to rugby league match play, reporting a mean metabolic power ~ 10 $W \cdot kg^{-1}$. Furthermore, time spent above what is considered a 'high' metabolic power (~20 $W \cdot kg^{-1}$) was ~7 min, depending on playing position. These values equate to an estimated rate of energy expenditure of ~15 $kJ \cdot kg^{-1}$ (Kempton et al., 2015). Whilst there is a precedence for metabolic power measurements in rugby league, it should be noted that such an approach might result in a large underestimation of energy expenditure, owing to an elevated energy expenditure during non-ambulatory periods after exercise (i.e. resting;

Buchheit, Manouvrier, Cassirame & Morin, 2015). Indeed, Highton et al. (2017a) reported a significant underestimation (~45%) of energy expenditure derived from GPS (~ 7 kcal·min^{-1}) *cf*. open-circuit spirometry (~13 kcal·min^{-1}) during a collision based repeated effort protocol. This systematic underestimation was largely explained by an increase in metabolism (above resting) during intermittent periods of rest (60 s) allowed between the three repeated efforts, suggesting that such methods should be used with caution when quantifying the metabolic cost of rugby league training and competition. However, the authors did report a moderate correlation between energy expenditure derived from GPS *cf*. open-circuit spirometry (r = .63), and was greater than high-speed running (r = .50). Oxendale and colleagues (2017) suggest that energy expenditure derived from GPS better reflects the physiological loads during intermittent running exercise than traditional speed categories (i.e. high-speed running) and is closely related with the direct assessment of energy expenditure (r = 0.89).

2.2.4 Internal Load (Perceptual)

In addition to the documented physiological responses, internal loads also manifest with significant perceptual loads during rugby league competition. Research has traditionally used session rating of perceived exertion (*s*RPE) to determine the perceived exercise intensity associated with rugby league training (Lovell et al., 2013) and match-play (Waldron et al., 2011; Johnston et al., 2013; McLean et al., 2010); values of ~7-8 AU immediately after rugby league match-play have been typically reported (Johnston et al., 2013). In rugby league, this measured *s*RPE is considered a valid, non-invasive 'global' measure of internal load (Foster et al., 2001; Lovell et al., 2014), which is often used to calculate global match load (i.e. summated *s*RPE), whereby *s*RPE (0-10 AU) is multiplied by playing time (min).

Summated session rating of perceived exertion (RPE) reveal similar positional differences to summated heart rate data, with ~240, ~435, and ~380 AU for forwards, adjustables, and outside backs, respectively (Waldron et al., 2011). Indeed, according to Waldron et al. (2011), approximately 40% (r^2 = 0.401) of the variance in *s*RPE was explained with summated heart rate. Players perception of effort are seemingly informed by both the external and internal (physiological) loads though, with total distance, distance covered high speed running (> 15 $km \cdot h^{-1}$), $\%HR_{peak}$ and collisions (collisions/min) correlated with changes in RPE (Lovell et al., 2013).

Although *s*RPE can provide a global measure of exercise intensity, it could also oversimplify the physically and mentally demanding construct of match-play (Weston, Siegler, Bahnert, McBrien & Lovell, 2015). More recently, the use of differential RPE (*d*RPE) has been suggested as a method to quantify and discriminate the internal loads associated with rugby (union) training, including individual session ratings for breathlessness (*d*RPE-B), upper/lower body muscle exertion (*d*RPE-U/L) and cognitive demands (*d*RPE-T; McLaren et al., 2017). McLaren et al. (2017) proposed that *d*RPE represent different dimensions of perceived exertion, thus providing a more detailed quantification of the internal loads experienced by players, beyond solely reporting *s*RPE. For example, *d*RPE-B was more closely correlated with RHIE training (r = 0.89), whilst dRPE-T was more closely correlated with skills training (r = 0.51). These data suggest that cognitive load (*d*RPE-T) is construct from different sensory information to other perceptual measures of internal load (e.g. sRPE). To date the cognitive load associated with rugby league training and match-play is not considered in the literature.

2.3 Response to Rugby League Activities

After rugby league match play, players will experience symptoms of fatigue, comprising sensations of tiredness and impaired neuromuscular function that can persist for several days (Twist et al., 2012; McLellan, Lovell & Gass, 2011a). Given the complex and varied stimulus of external load (e.g. running and collision) imposed on players (see section 2.2.1), the mechanisms of fatigue from rugby league match-play are also complex. Specifically, the external demands of rugby league competition are characterised with intermittent efforts, requiring repeated accelerations and decelerations (Waldron et al., 2011; Gabbett, 2012). These repeated eccentric muscle actions (i.e. accelerating then decelerating) are known to cause myofibrillar disruption and an inflammatory response, leading to impaired excitation-contraction coupling (Hyldahl & Hubal, 2014; Peake, Neubauer, Della Gatta & Nosaka, 2016). In addition to these eccentrically biased actions, the number of total and high impact collisions (>7.1G) are also correlated with indirect markers of muscle damage (Oxendale et al., 2016). Unlike the traditional mechanism of exercise induced muscle damage (i.e. eccentric activity), it appears that the resultant fatigue from these high impact collisions is likely due to the blunt trauma associated with tackling and being tackled (Twist et al., 2012; McLellan et al., 2011; Naughton, Miller & Slater, 2017; Naughton, Miller & Slater, 2018). Indeed, several studies have observed immediate and prolonged (0 – 48 h) decrements in neuromuscular function (Duffield, Murphy, Snape, Minnet & Skein, 2012; Johnston et al., 2013; McLellan et al., 2011; Twist et al., 2012; Oxendale et al., 2016), elevated circulating blood myofibril proteins (McLellan et al., 2010; Twist et al., 2012; Oxendale et al., 2016) and altered subjective ratings of soreness and wellbeing (Johnston et al., 2013; Twist et al., 2017; Twist et al., 2012; Oxendale et al., 2016) lasting between 24 – 48 h, before returning to baseline within ~60-72 h post match. Interestingly, a season long analysis of subjective muscle soreness observed that players perceive to be constantly sore throughout the season (Fletcher et al., 2016). The authors documented a significant relationship between match loads (playing time and total number of collisions) and higher ratings of lower (r = 0.58, r = 0.31; respectively) and upper body (r = 0.63, r = 0.34) muscle soreness (Fletcher et al., 2016). These data, coupled with inconsistent recovery periods between matches (~5 – 10 days; Twist et al., 2017), suggest that players' fatigue and recovery from match-play should be monitored to ensure adequate recovery and optimum performance in subsequent competition. Several studies have described the impact of rugby league competition on fatigue and was recently reviewed elsewhere (Twist & Highton, 2013). Defining fatigue has been notoriously difficult (Enoka & Duchateau, 2008). Physiologists have historically described fatigue as an acute exercise induced decline in maximal force generating capacity (Edwards, 1981), whereas applied exercise scientists have more broadly defined fatigue as sensations of tiredness associated with a reduced capacity for maximal performance (Knicker, Renshaw, Oldham & Cairns, 2011; Abbis & Laursen, 2005; Halson, 2014). For clarity, fatigue is defined herein as a symptom whereby physical and cognitive function is limited by either/or performance fatigability and perceived fatigability (Enoka & Duchateau, 2016). The following sections will briefly discuss the most commonly reported methods of assessing fatigue within the scientific literature relating to rugby league.

2.4 Measures of Fatigue

2.4.1 Subjective Assessment of Fatigue

Several subjective measures have been used to monitor recovery and fatigue in rugby league players (Twist et al., 2012; Johnston et al., 2013). In team sports, subjective measures of fatigue include profile of mood states (POMS; Morgan, Brown, Raglin, O'Conner, Ellickson, 1987), daily analysis of life demands for athletes (Rushall, 1990), recovery-stress questionnaire (Kellmann & Kallus, 2001), and total quality recovery scale (Kentta & Hassmen, 1998). However, the most common method of assessing subjective fatigue after rugby league match-play involves players rating their perceived fatigue and muscle soreness using a Likert scale (Twist et al., 2012; McLean et al., 2010; Oxendale et al., 2016). These studies have consistently observed increased ratings of subjective fatigue and muscle soreness in the days after matches, for up to four days (Twist et al., 2012; McLean et al., 2010). Furthermore, positional differences exist for subjective fatigue, given the stark differences in external loads imposed on individual players (Oxendale et al., 2016; Twist et al., 2012). This has implications for forward playing positions that are known to perform more collision actions during a match (Oxendale et al., 2016). Interestingly, perceptual measures have been correlated with external loads associated with match play, including the number of collisions a player is involved in (Twist et al., 2012). However, limited research exists to demonstrate any relationship between various match loads (physical and technical) and post-match subjective fatigue and recovery.

2.4.2 Biochemical and Endocrine Markers of Fatigue

Intense exercise and muscle trauma will result in disturbances to skeletal muscle structures that are associated with leakage of several intracellular components (e.g. muscle proteins), that subsequently become elevated within the bloodstream (Baird, Graham, Baker & Bickerstaff, 2012). It is therefore possible that these biochemical and hormonal markers can help determine the immediate fatigue and prolonged recovery following matches. Indeed, muscle damage is often monitored using indirect blood markers following rugby league match play. Creatine kinase is the most common blood marker of muscle damage following rugby league competition, with elevated blood concentrations (~100 - 150%) reported 24 – 48 h following matches (McLellan et al., 2011; Twist et al., 2012; Oxendale et al., 2016; Tavares, Smith & Driller, 2017). Several studies have observed a relationship between the number of collisions (tackle or being tackled) and plasma CK concentration, suggesting that the amount of tissue damage is proportionate to the amount of collisions (Cunniffe et al., 2010; Twist et al., 2012). This relationship also suggests that creatine kinase is unable to distinguish damage from blunt trauma (i.e. collisions) or mechanically induced muscle damage (i.e. decelerations). Measuring creatine kinase concentrations within the blood is costly, invasive and demonstrates a poor temporal relationship with perceptual and performance changes (Margaritis, Tessier, Verdera, Bermon & Marconnet, 1999; Twist et al., 2012). As such, it is suggested that when creatine kinase is used in isolation it is not a useful marker of fatigue and recovery in rugby league players (Twist et al., 2012).

Hormonal disturbances have also received research interest as indirect markers of fatigue following rugby league match play, namely cortisol (McLellan et al., 2011; McLean et al., 2010). Indeed, McLellan et al. (2011a) observed elevated salivary cortisol from pre (~10 $nmol \cdot L^{-1}$) to 30 min and 24 h (~22 $nmol \cdot L^{-1}$; 117% increase) after rugby league match play, before returning to resting values by 48 h (~9.5 $nmol \cdot L^{-1}$). These increased cortisol concentrations post-match are suggested to be a result of the psychological (anxiety and stress) and physical (high intensity running with physical collisions) load associated with competition (McLellan et al., 2011a). Interestingly, salivary cortisol increased ~30% before the start of the match (~30 min). The authors suggested that these changes were due to cognitive anticipation and perceived anxiety for the upcoming competition (McLellan et al., 2011a). These hormonal disturbances suggest that there is a significant mental, as well as physical, stress during rugby league match play.

2.4.3 Neuromuscular Function

As described in section 2.3, decrements in neuromuscular function are observed after rugby league matches that offer an insight into the fatigue and recovery from the activities performed (Duffield et al., 2012; Johnston et al., 2013; McLellan et al., 2011; Twist et al., 2012; Oxendale et al., 2016). Jump tests have been implemented to monitor fatigue after rugby league competition, as they assess stretch shortening ability of the lower limbs (Komi, 2000) and are sensitive to muscular fatigue (Twist et al., 2012; McLean et al., 2010; McLellan et al., 2011). Indeed, transient reductions in CMJ performance (peak power and flight time) are observed 24 h after rugby league competition (peak power ~20-40% lower; McLellan et al., 2012; McLellan et al., 2011; flight time ~4% lower; Twist et al., 2012). Duffield et al. (2012) also reported decrements (8-12%) of peak isometric forces during maximal voluntary contractions of the knee extensor immediately after match-play and for up to two hours after exercise. Useful mechanistic data describing the relative contribution of central and peripheral fatigue can be determined using maximal voluntary contractions with isolated muscle stimulation. Interestingly, voluntary activation (~90%) was unchanged after matches, suggesting that post match fatigue (i.e. impaired muscle function) may reflect failure of the contractile unit rather than an impaired motor unit recruitment via reduced neural drive (Duffield et al., 2012).

Notwithstanding the approach provides only isolated assessments of single muscle groups (e.g. they poorly reflect the sport specific movements of rugby) and the challenges of using this in a real-world setting (Twist & Highton, 2013). The use of isometric dynamometry and muscle stimulation offers useful mechanistic insight to determine the central and peripheral contributions to fatigue after rugby match play. Further studies are required to elucidate the muscle fatigue after movements that replicate rugby activities.

2.5 Mental Fatigue

Angelo Mosso (1915) initially observed that muscular fatigue occurred sooner in professors of physiology after delivering long lectures. This phenomenon was later termed mental fatigue, and is described as a psychobiological state resulting from periods of prolonged demanding cognitive activity (Marcora et al., 2009). Since its conception, mental fatigue has been characterised by a combination of subjective (a lack of energy, increased feelings of tiredness and decreased motivation; Boksem, Meijman & Lorist, 2006; Boksem & Tops, 2008), behavioural (impaired cognitive performance, including declines in accuracy and reaction time; Marcora et al., 2009; Möckel, Beste & Wascher, 2015) and physiological (altered brain activity; Brownsberger et al., 2013) responses.

The adverse effects of mental fatigue on cognitive tasks (Boksem et al., 2005; Boksem et al., 2006; Lal & Craig, 2001; Lorist, Boksem & Ridderinkhof, 2005; Marcora et al., 2009) and endurance performance (Van Cutsem et al., 2017; Marcora et al., 2009) are well-documented. The current understanding of mental fatigue and physical performance is largely derived from laboratory-based research during endurance tasks. Therefore, the ability to transfer such findings to the distinct demands of team sport performance is limited. That said, negative effects of mental fatigue have recently been reported on physical and technical performance during soccer match-play (Smith et al., 2015; Smith et al., 2016; Smith et al., 2017; Coutihno et al., 2018) and cricket performance (Veness, Patterson, Jeffries & Waldron, 2017). Such effects of mental fatigue are not considered to alter performance via physiological changes (Pageaux et al., 2014) or altered neuromuscular function (Pageaux et al., 2013; Martin, Thompson, Keegan, Ball & Rattray, 2015; Pageaux, Marcora, Rozand & Lepers, 2015). Rather, these effects are mediated by an increased perception of effort (Martin, Meeusen, Thompson, Keegan & Rattray, 2018). Although the increased perception of effort during exercise due to mental fatigue is well documented (Marcora et al., 2009; Martin et al., 2015; Pageaux et al., 2014; Pageaux et al., 2013; Pageaux et al., 2015; Smith et al., 2016), the mechanisms underpinning this psychobiological state are poorly understood.

2.5.1 Mechanisms of Mental Fatigue

It has been postulated that mentally demanding efforts result in an accumulation of extracellular cerebral adenosine (Martin et al., 2018). This accumulation of adenosine naturally occurs progressively throughout the waking day before dissipating with sufficient sleep and will accumulate greater in sleep deprived individuals (Porkka-Heiskanen, Strecker & McCarley, 2000; Porkka-Heiskanen, 1999). Brain metabolic activity increases under cognitively demanding conditions and is localised depending on the specific task (Gusnard & Raichle, 2001). Indeed, performance of a mentally fatiguing task is associated with increased activation of the anterior cingulate cortex (ACC), an area of the prefrontal cortex responsible for generating perception of effort (Lorist et al., 2005; Marcora et al., 2009). After cognitively demanding tasks, cerebral adenosine, a neuromodulator that inhibits brain excitatory neurotransmitters (e.g. dopamine; Myers & Pugsley, 1986), is known to accumulate within the active region of the brain (Pardo, Pardo, Janer & Raichle, 1990). Given the inhibitory mechanism of adenosine, it is postulated that greater stimulatory input to the sensory areas of the cerebral cortex -from the motor regions of the brain- are needed to produce a given motor output (Marcora et al., 2009). Additionally, a greater corollary discharge is needed from the motor cortex to the anterior cingulate cortex. The adenosine is thought to increase mental fatigue and subsequently reduce exercise performance via two mechanisms: (i) by reducing motivation and (ii) increasing perception of effort during subsequent exercise (Figure 2.1; Martin, Meeusen, Thompson, Keegan & Rattray, 2018). An altered motivation or willingness to exert effort following mental fatigue is associated with an impaired dopamine release (Myers & Pugsley, 1986). Growing literature exists to suggest that perception of effort is a key modulator of the conscious self-regulation of exercise performance and exercise tolerance, outlined in the psychobiological model (Marcora, Bosio & de Morree, 2008). Relatively few studies have reported decreased subjective motivation after mental fatigue (Martin et al., 2015; Brown & Bray, 2017). Indeed, an unchanged motivation following mental fatigue is in contrast to the mechanism of mental fatigue outlined in the model below (Martin et al., 2018). This highlights a limitation to this proposed model, but might suggest a limitation of reporting subjective motivation more broadly, given that such results are likely confounded by social desirability bias and as such, individuals might avoid reporting low motivation (Martin et al., 2018; Veness et al., 2017; Badin et al., 2016). However, this phenomenon is not limited to subjective motivation and rather a limitation of most self-report data.

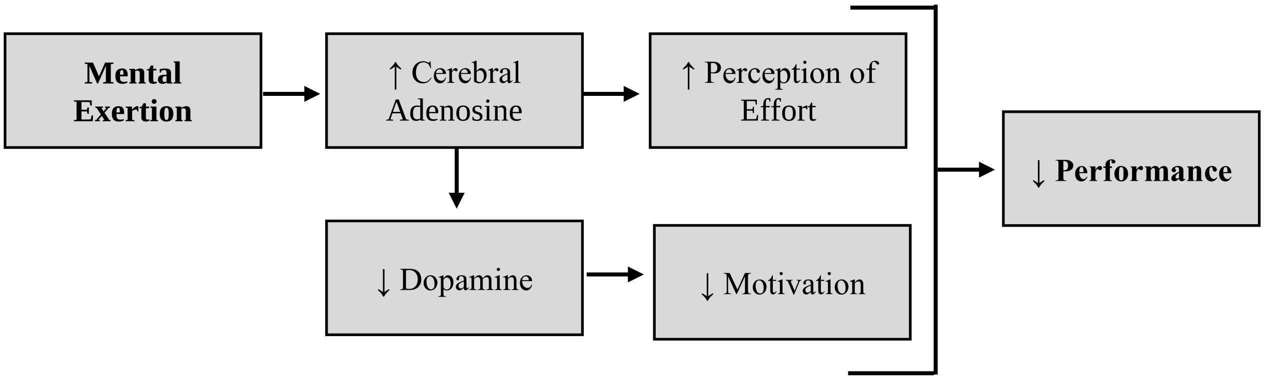

Figure 2.1. Schematic representation of the mechanism of mental fatigue, proposed by Martin et al. (2018).

2.5.2 Mental Fatigue Inducing Interventions

Mental fatigue has been achieved after prolonged (30-90 min) cognitively demanding tasks that comprise elements of response inhibition. Response inhibition is defined as the executive function that prevents unwanted motor responses and is considered a central component of decision-making processes in humans (Mostofsky & Simmonds, 2008). Although several cognitively demanding tasks have been used to elicit mental fatigue, the most commonly used methods include 30-60 min modified Stroop word-colour task (Pageaux et al., 2015; Pageaux et al., 2014; Smith et al., 2016; Badin et al., 2016) and 90 min AX-continuous performance task (AX-CPT; Brownsberger et al., 2013; MacMahon, Schücker, Hagemann & Strauss, 2014; Marcora et al., 2009; Martin et al., 2015; Pageaux et al., 2013; Smith et al., 2015). The Stroop task requires participants to respond verbally (paper based; Smith et al., 2016) or by pressing the correct button (computer based; Badin et al., 2016; Pageaux et al., 2015; Pageaux et al., 2014) as quickly as possible with the colour each word is printed (red, blue, yellow and green) and not the meaning of the written word. For example, if the word "Green" was printed in Blue ink, the correct response would be "Blue". The Stroop task is commonly used to elicit mental fatigue in team sports research (Badin et al., 2016; Smith et al., 2016), given the response inhibition and the potential to incorporate audio responses likely increase the mental demand experienced (Smith et al., 2016). However, more research is required to determine the effects of more ecologically valid methods of eliciting mental fatigue. For example, players and coaches suggest that activities such as other commitments (e.g. media and sponsorship commitments), change in environment, over-analysis and potentially a lack of experience (e.g. young players perceive mental fatigue more) contribute to players and coaches perceived mental fatigue (Martin et al., 2019).

The AX-CPT is a similar cognitive task completed on a computer, whereby individual letters are presented on a computer screen (300 ms) at regular intervals (1,200 ms). Participants are required to press the right button when the letter 'A' and 'X' are presented in sequence, and for all other letters the left button must be pressed. These cognitive tasks (Stroop and AX-CPT) have repeatedly been utilised to elicit mental fatigue due to their specific demands, including response inhibition, sustained attention, working memory and error monitoring (Carter et al., 1998; MacLeod & MacDonald, 2000; Pageaux et al., 2014), the combination of which are associated with activation of the ACC (Barch et al., 1997; Pardo et al., 1990). As discussed previously (section 2.5.1), this area of the prefrontal cortex is affected by mental fatigue (Lorist et al., 2005; Marcora et al., 2009).

Most research assessing the effect of mental fatigue on physical performance have included time-matched control trials, including either magazine reading (Smith et al., 2016; Veness et al., 2017) or watching an emotionally neutral documentary (Brownsberger et al., 2013; Duncan, Fowler, George, Joyce & Hankey, 2015; Marcora et al., 2009; MacMahon et al., 2014; Martin et al., 2015; Pageaux et al., 2013; Smith et al., 2015). These emotionally neutral control tasks have been selected due to their ability to induce a stable heart rate, with minimal effects on mood (Silvestrini & Gendolla, 2007; Smith et al., 2016). Most importantly, these tasks have consistently resulted in unchanged subjective ratings of mental fatigue (Smith et al., 2016; Veness et al., 2017; Van Cutsem et al., 2017).

2.5.3 Effects of Mental Fatigue

Research has been conducted on the effects of mental fatigue during tasks such as driving (Brown, 1994; Lal & Craig, 2001) and flight simulation (Borghini, Astolfi, Vecchiato, Mattia & Babiloni, 2014). In these studies, mental fatigue was associated with sensations of tiredness, decreased motivation and reduced task directed attention (Lal & Craig, 2001; Borghini et al., 2014), and resulted in changes in cognitive function (e.g. changes in attention and reaction time) and technical performance (e.g. flight simulation tasks; Borghini et al., 2014). However, until relatively recently, there existed relatively little information on the effects of mental fatigue on sports and exercise performance.

2.5.3.1 Mental Fatigue and Exercise Performance

Endurance performance is impaired after completion of a mentally fatiguing task (Marcora et al., 2009; Martin et al., 2018; Van Cutsem et al., 2017; Smith et al., 2018). The first study to describe such effects was conducted by Marcora et al. (2009), whereby 16 healthy participants cycled to exhaustion at 80% of their peak power output, following 90 min of a mentally demanding task (AX-CPT). The authors reported a 15% reduction in time to exhaustion following mental fatigue. Given that mental fatigue had unclear effects on physiological markers (heart rate and blood lactate), it was concluded that the impaired cycling performance were due to the observed significantly higher RPE (16 *cf*. 18 AU). Subsequent studies have documented the adverse effects of mental fatigue on various physical tasks. These include self-paced running protocols, whereby 3 (MacMahon et al., 2014) and 5 km (Pageaux et al., 2014) running times were increased by 2 and 5%, respectively, as a result of pre-exercise mental fatigue. More recently, the effects of mental fatigue have been observed during intermittent self-paced exercise (Smith et al., 2015). Following mental fatigue (90 min AX-CPT), 10 male team sports players covered less total distance (2%) and distance at low intensities (3%;

walking, jogging and running, <50% of maximum effort) during a 45 min self-paced intermittent running protocol (Smith et al., 2015). Similar negative effects of mental fatigue have been observed during intermittent running to exhaustion, with ~14% less distance covered during the Yo-Yo intermittent recovery test (Smith et al., 2016). Completion of a 30 min incongruent Stroop task, resulted in decreased distance covered during the YoYo IRT. As with other studies, mental fatigue resulted in an increased RPE during exercise (Smith et al., 2016).

It appears that the previously reported effects of mental fatigue are less apparent during more ecologically valid settings simulating the intermittent and competitive nature of team sports (Coutinho et al., 2018; Badin et al., 2016). During small sides games (SSG) of soccer (5 vs 5; 6 – 15 min), mental fatigue increased perception of exertion (ES = 0.39), yet movement speeds during the SSGs remained relatively unchanged (Coutinho et al., 2018; Badin et al., 2016). The authors concluded that a speed accuracy trade off occurred in the presence of mental fatigue (Badin et al., 2016), suggesting that individuals consciously maintain movement speeds whilst subsequent technical performance (e.g. accuracy of passes) is impaired. These data highlight the complex nature of team sports performance, given the combination of physical and mental loads. As such, further research on the effects of mental fatigue on team sports performance that incorporates appropriate physical, physiological, technical and cognitive loads is warranted.

Several studies have found no effect of mental fatigue on neuromuscular function during subsequent maximal strength and power assessments (Pageaux et al., 2013; Pageaux et al., 2015; Martin et al., 2015). For example, when participants performed maximal voluntary contractions (MVC) of the knee extensors following mental fatigue, there were no effects on the peripheral (i.e. peak torque and peak twitch response), or central (i.e. voluntary activation) constructs of neuromuscular function (Pageaux et al., 2013; Martin et al., 2015; Pageaux et al., 2015). Similarly, Martin et al. (2015) observed unchanged countermovement jump (CMJ) performances (jump height and peak power) following mental fatigue. Taken together, these studies suggest that mental fatigue is limited to exercise of a prolonged duration, and these deleterious effects can be overcome in the short-term.

Most mental fatigue research include amateur athletes (Table 2.1), which is interesting given that the level of the athlete might influence an individual's response to mentally demanding tasks (i.e. mental fatigue; Martin et al. 2016). Professional road cyclists exhibited greater resistance to the deleterious effects of mental fatigue (30 min Stroop), with no changes in perception of effort and time trial performance (20 min cycling) when compared to amateur cyclists (i.e. increased perception of effort and impaired performance; Martin et al., 2016). The authors suggest that elite cyclists possess a greater resistance to mental fatigue from either training or genetics (Martin et al., 2016). More research is required to determine the effect playing standard might influence the response to mental fatigue in team sport performance.

2.5.3.2 Mental Fatigue and Cognitive Function

Mental fatigue has been shown to impair performance during computer based cognitive function tasks (Boksem et al., 2005; Boksem et al., 2006; Lorist et al., 2005; Lorist et al., 2000). These effects are associated with reduced reaction times (Boksem et al., 2005), increased number of errors (Duncan et al., 2015), and a reduction in goal directed attention (Boksem et al., 2005). Boksem et al. (2005) reported slower reaction times (5.2 %), and an increase in errors (8.2%; $P < 0.005$) in the first 45 min compared to the final 45 min of a prolonged (3 hour) computer based visual attentional task. Prolonged performance of the AX-CPT has elicited similar reductions in cognitive function when performed for 90 min, including greater number of errors in the final 15 min (5.2 ± 3.1) compared to the first 15 min (2.4 ± 0.9; $P = 0.018$; Smith et al., 2015). Shorter duration mentally fatiguing tasks result in similar effects on cognitive function (Veness et al., 2017). For example, cognitive function was impaired during a 30 min incongruent Stroop task, performed on a tablet devise, whereby more errors and slower reaction times were reported during the final 15 min compared to the first 15 min (Veness et al., 2017). These data suggest that 30 min of a mentally fatiguing task (e.g. incongruent Stroop) is adequate to induce mental fatigue (Veness et al., 2017; Smith et al., 2016), to similar extents to the longer duration mental fatiguing tasks lasting between 60-180 min (Boksem et al., 2005; Pageaux et al., 2013; Marcora et al., 2009). However, inter-individual differences during these response inhibition tasks occur with professional cyclists exhibiting better inhibitory control then amateur cyclists when performing 30 min Stroop task (Martin et al., 2016).

2.5.3.3 Mental Fatigue and Technical Performance

Recent research has described the effects of mental fatigue on the performance of fundamental motor skills during laboratory-based experiments (Duncan et al., 2015; Rozand, Lebon, Papaxathis & Lepers, 2015). They found that several fundamental motor skills were impaired following mental fatigue, including impaired anticipation timing, manual dexterity and goal directed arm movements (Duncan et al., 2015; Rozand et al., 2015). Similar decrements in fundamental motor skills, associated with mental fatigue, have been reported during soccer specific skill tests performed in controlled (Smith et al., 2016) and applied (Badin et al., 2015; Smith et al., 2017) settings. Following mental fatigue induced by 30 min incongruent Stroop task, 12 male soccer players performed a soccer specific decision-making task (Smith et al., 2016). The task involved film-based simulations whereby the participant would observe a period of offensive soccer play before making a decision based on the information available (e.g. number and position of offensive and defensive players). Further to making the decision, players were required to complete the appropriate action (e.g. passing to any player, dribbling the ball around a defender or taking a shot at goal), as quickly as possible, with a football placed in front of them. The authors reported impairments in overall response time (*likely* higher; ES

= 0.49) and decision making accuracy (*very likely* lower; ES = -0.89) following mental fatigue compared to a control trial (time-matched magazine reading). However, it was concluded that "future research should take a more practical approach to assessing the impact of mental fatigue on soccer performance" (Smith et al., 2016). Subsequent research from Smith and colleagues (2016) assessed the soccer specific technical performance of 14 experienced soccer players (playing experience = 13.6 ± 3.2 y) using the Loughborough Soccer Shooting Test (LSST) and Loughborough Soccer Passing Test (LSPT). Following the mentally fatiguing task, players performed less accurate passes (LSPT; 47.4% increase in penalty time; ES = 0.76) and less accurate (54% increase in points per shot; ES = 0.75), slower shots at goal (LSST; 4% decrease in shot speed; ES = 0.75). Measures of movement speeds during these technical skills tests remained unchanged, suggesting that a speed accuracy trade of occurred (Smith et al., 2016), whereby individuals focussed their attention on specific elements of the task depending on the instructions provided. For example, when a timed passing accuracy soccer task is performed and the participants are instructed to perform the test as quickly and accurately as possible, individuals passing accuracy becomes impaired whilst movement speeds are maintained to avoid associated time penalties (Smith et al., 2016). Similar research, conducted in more ecologically valid settings, assessed the effects of mental fatigue (30 min computerised Stroop task) on technical skill performance during small sided games (SSG) of soccer (Badin et al., 2016). Performance analysis throughout these SSG (15 min, 5 vs 5), found reductions in passing accuracy (-2.1%, ES = -0.25), quantity of positive involvements (-10.1%, ES = -0.73), possession (-9.6%, ES = -0.63), more ball control errors (44.5%, ES = 0.61) and fewer successful tackles (-26.2%, ES = -0.76; Badin et al., 2016). Similarly, the movement speeds remained unchanged following mental fatigue, providing further evidence that a speed accuracy trade off will occur during states of fatigue (mental and physical). Currently no research exists describing the effect of mental fatigue on rugby league performance (movement or technical). Furthermore, the extent of mental load during actual match-play is currently unknown.

2.5.4 Measures of Mental Fatigue

Given mental fatigue's effects on performance, a specific and objective measure to determine the presence and magnitude of mental fatigue is warranted (i.e. to determine whether an individual is mentally fatigued after a cognitively demanding task). As discussed in section 2.5, mental fatigue can manifest in a combination of behavioural, subjective and physiological responses (Boksem et al., 2006; Marcora et al., 2009). As such, several measurement tools (behavioural, subjective and physiological) are required to determine the manifestation of mental fatigue. The most commonly used methods for quantifying mental fatigue relate to behaviour (e.g. cognitive performance tests) and subjective (e.g. assess how mentally fatigued an individual feels) measures. Changes in behaviour are often measured using cognitive performance tests, whereby reaction time and response accuracy are recorded (Stroop test; Veness et al., 2017; AX-CPT; Marcora et al., 2009). Subjective markers of mental fatigue include the use of visual analogue scales (VAS mental fatigue and motivation; Smith et al., 2016), Brunel Mood Scale (BRUMS; Terry, Lane & Fogarty, 2003; Marcora et al., 2009) and rating of perceived exertion (RPE: Marcora et al., 2009; Smith et al., 2015).

The use of VAS to determine the extent of mental fatigue, mental effort and motivation involves rating subjective feelings, between 'none at all' (0) and 'maximal' (100; Smith et al., 2015). Increased ratings of subjective mental fatigue (VAS) are associated with elevated perception of effort, impaired cognitive function and decrements in subsequent physical performance (Van Cutsem et al., 2017). Although this subjective measure appears to be sensitive to mental fatigue, the method whereby VAS data is gathered (i.e. asking participants how mentally fatigued they are) might encourage response bias (Van Cutsem et al., 2017).

Previously, authors have suggested that mental fatigue was successfully achieved, as evidenced by declines in cognitive performance with a concomitant increase in subjective measures of mental fatigue (Marcora et al., 2009; Smith et al., 2015). Other subjective measures, including the NASA-TLX (Hart & Staveland, 1988), have been used to determine subjective ratings of six subscales (mental demand, physical demand, temporal demand, performance, effort and frustration) during tasks after a mentally fatiguing task (Pageaux et al., 2014; Pageaux et al., 2015). The authors reported that subjective mental demand was rated significantly higher after mental fatigue, during subsequent cognitive tasks (P <0.05) and a 5 km running time trial (P <0.01; Pageaux et al., 2014). Although the NASA-TLX is not a measure of mental fatigue, it can provide data to quantify mentally fatiguing situations (i.e. increased subjective mental demand). Such data would allow for a greater understanding of the causes of mental fatigue in more complex and dynamic environments such as competitive or simulated rugby league match play.

Electroencephalography (EEG) is a method of assessing the electrical activity of specific regions of the brain. With mental fatigue, EEG activity is elevated in the pre-frontal cortex (Waschner et al., 2014; Brownsberger et al., 2013), the region of the brain suggested to be responsible for complex cognitive behaviour and decision making (Miller & Cohen, 2001). Previously, Brownsberger et al. (2013) reported increased EEG activity of the prefrontal cortex after 90 min of a mentally demanding task (AX-CPT) compared to watching an emotionally neutral documentary (World Class Trains – The Venice Simplon Orient Express). Interestingly, subsequent self-paced cycling performance (10 min at fixed RPE) was impaired to a greater extent in individuals that reported increased subjective ratings of fatigue with an elevated EEG activity of the prefrontal cortex (Brownsberger et al., 2013). However, given the specialist equipment required during an EEG and the signal to noise issues inherent during exercise (Crabbe & Dishman, 2004), these methods are seldom used within physical performance research (Brownsbereger et al., 2013). In light of the reviewed literature and the well-described effects of mental fatigue mean that exploring strategies to reduce this mental fatigue are warranted. One such strategy is caffeine supplementation.

2.6 Caffeine as an Ergogenic Aid

Caffeine is a widely used substance in sports, given its well established ergogenic effect on several physical and cognitive activities (Goldstein et al., 2010). Once consumed, caffeine is quickly absorbed through the gastrointestinal tract before being metabolised in the liver, with elevated caffeine concentration observed in the blood stream within 15 – 45 min (Harland, 2000). Peak plasma concentrations of caffeine occur around one hour after consumption (Robertson et al., 1978). Subsequently, caffeine is rapidly distributed and due to its high lipid solubility, it readily crosses the blood brain barrier where it can exert its effect on the CNS (McLellan, Caldwell & Lieberman, 2016; McCall, Millington & Wurtman, 1982). Several mechanisms have been suggested for the effects of caffeine supplementation on sport performance. These physiological mechanisms of caffeine include, (i) an increased mobilisation of intracellular calcium (Herman-Frank, Lüttgau & Stephenson, 1999), (ii) increased fat oxidation (Costill, Dalsky & Fink, 1978), (iii) increased plasma β-endorphin concentrations (Laurent et al., 2000), (iii) increased testosterone concentrations (Beaven et al., 2008), and (iv) blocking of adenosine receptor sites within the central nervous system (CNS; Davis et al., 2003). Early research posited the ergogenic effect of caffeine on endurance performance was related to the stimulatory effect of caffeine on adrenaline secretion, leading to an increased oxidation of free fatty acids and subsequent muscle glycogen sparing (Costill et al., 1978; Erickson, Schwarzkopf & McKenzie, 1987). The secretion of β-endorphins also pose an ergogenic effect of caffeine on exercise performance, given that the analgesic properties of β-endorphins might result in a reduction in pain perception (Grossman & Sutton, 1985). Extensive research now exists postulating that the ergogenic effects of caffeine are largely due to central factors, linked to the blocking of adenosine receptor sites within the CNS (Davis et al., 2003; Kalmar & Cafarelli, 2004; Goldstein et al., 2010). Adenosine accumulation, specifically within the brain, is associated with a reduction in motivation and increased perception of effort during subsequent exercise (Figure 2.1; Martin et al., 2018). Caffeine is similar in structure to adenosine and is able bind to adenosine receptors, thus blocking their action. As such, caffeine has successfully inhibited several of the adverse effects of cerebral adenosine accumulation, including impaired brain excitatory neurotransmitters (e.g. dopamine; Myers & Pugsley, 1986) and lower arousal (Porka-Heiskanen, 1999).

2.6.1 Caffeine Supplementation

Caffeine supplementation, at doses ranging from 1-6 $mg \cdot kg^{-1}$ result in improved performance during endurance, intermittent and all out efforts (Ganio, Klau, Casa, Armstrong & Maresh, 2009; Goldstein et al., 2010). Lower doses of caffeine (< 1 $mg \cdot kg^{-1}$) have limited effects on sport performance (Kovacs, Stegen & Brouns, 1998). Conversely, higher doses (9 - 13 $mg \cdot kg^{-1}$) are known to improve endurance performance similar to moderate doses of caffeine (5 $mg \cdot kg^{-1}$; Pasman, Van Baak, Jeukendrup & De Haan, 1995). Yet, the proposed benefits of caffeine on increase calcium mobilisation only occur at doses that are considered toxic in humans (*in-vitro* mouse muscle fibres; Neyroud et al., 2019) and are therefore unlikely to improve performance even when supplemented at higher doses (~ 9 $mg \cdot kg^{-1}$). Additionally, these higher doses (>6 $mg \cdot kg^{-1}$) come with potential deleterious side effects, including; gastrointestinal upset, nervousness, inability to focus, headache and disturbed sleep (Graham & Spreit, 1995; Jura, Townsend, Curhan, Resnick & Grodstein, 2011).

Within sport performance, caffeine is ingested in one of three ways; (i) a drink (including mouth rinsing), (ii) capsule or tablet and (iii) chewing gum. The ergogenic effects of caffeine are similar, regardless of the form of caffeine, notwithstanding significantly faster (~70%)

absorption times when caffeinated gum is administered (Kamimori et al., 2002; Wickman & Spriet, 2018). However, given the rapid absorption and peak in plasma caffeine (~1 h) after caffeine supplementation, most research (Burke, 2008; Graham, 2001; Salinero, Lara & Del Coso, 2018) and current guidelines (Goldstein et al., 2010) suggest that athletes ingest moderate doses (3 – 6 $mg \cdot kg^{-1}$) of anhydrous caffeine one hour before the commencement of exercise. It is suggested that there are responders and non-responders to caffeine (Southward, Rutherfurd-Markwick, Badenhorst & Ali, 2018), however this is likely dependent on the dose and mode of exercise/task. The following sections will explore the potential effects of caffeine on the physical, cognitive and technical performance associated with team sport, specifically relating to rugby league performance.

2.6.2 Caffeine and Exercise Performance

The ergogenic effects of caffeine are present across a variety of exercise modalities (endurance >30 min, Greer, Friars & Graham, 2000; muscle strength, Kalmar & Cafarelli, 1999; RHIE, Stuart, Hopkins, Cook & Cairns, 2005; for a review see Graham, 2001; Burke, 2008; Davis & Green, 2009). Several studies have examined the potential for caffeine ingestion, through acute supplementation (3 – 6 $mg \cdot kg^{-1}$), to increase plasma caffeine concentrations and subsequently have an ergogenic effect. Indeed, caffeine ingestion (3 – 4 $mg \cdot kg^{-1}$) is ergogenic when supplemented before performance indicative of rugby league match-play (Clarke, Highton, Close & Twist, 2019; Del Coso et al., 2012; Wellington, Leveritt & Kelly, 2017). Wellington et al. (2017) documented the effect of caffeine ingestion (300 mg caffeine tablets, ~3-4 $mg \cdot kg^{-1}$) during subsequent repeated high intensity effort performance in rugby league players. Eleven semi-professional rugby league players completed three sets of a repeated high intensity effort (RHIE) test (Austin, Gabbett & Jenkins, 2013), comprising 3 x 20 m sprints and 5 x 10 m sprints with simulated contacts (11 kg tackle bag). Whilst no significant differences were observed in average (169 ± 11 *cf.* 164 ± 12 $b \cdot min^{-1}$) and maximum (186 ± 10 *cf.* 185 ± 9 $b \cdot min^{-}$

^{1}) heart rate, blood lactate concentrations (9.0 ± 2.4 *cf.* 8.3 ± 2.7 mmol·L) and RPE during caffeine compared to placebo trials, eight out of eleven participants improved maximum sprint speeds in the caffeine trial. Improvements in overall sprint times (9 x 20 m sprints) were also observed in the caffeine (28.46 ± 1.4 s) compared to the placebo trial (28.77 ± 1.7 s; ES = 0.18). These findings were attributed to a dampened perception of effort and pain, leading to more work been completed. Although the 1% improvement in RHIE performance was described as meaningful, the authors concluded that more ecologically valid research must be conducted to determine the effects of caffeine ingestion on situations that better replicate actual rugby league match play.

Del Coso et al. (2012) recruited 26 elite male rugby league players that completed simulated matches during training (2 x 30 min halves with a 10 min rest at half-time) on two separate occasions, 60 min after consuming either a caffeine (3 $mg·kg^{-1}$) or a taste-matched placebo drink (250 ml). Total distance was higher in the caffeine (5139 ± 475 m, ~86 $m·min^{-1}$) compared to placebo trial (4749 ± 589 m, ~79 $m·min^{-1}$; $P = 0.01$, ES = 0.74), because of significant increases in distance covered during the second half ($P = 0.01$; ES = 0.94). Running speeds were also improved in the caffeine trial whilst jogging (6 – 12 $km·h^{-1}$; ES = 0.41), cruising (12 – 14 $km·h^{-1}$; $P = 0.04$; ES = 0.31), striding (14 – 18 $km·h^{-1}$; ES = 0.52), high intensity running (18 – 20 $km·h^{-1}$; $P = 0.01$; ES = 0.47), and sprinting (> 20$km·h^{-1}$; ES = 0.62). However, players' maximum (189 ± 12 *cf.* 185 ± 12 $b·min^{-1}$) and average (151 ± 11 *cf.* 145 ± 8 $b·min^{-1}$) heart rate remained unchanged throughout the caffeine compared to placebo trial. Unfortunately, players perception of exertion (RPE) during or after the simulated rugby league matches was not reported, which may have gone some way to explain the findings of increased running speeds given no physiological changes (HR). Furthermore, it is unknown whether the increased running speeds and total distance were a direct result of caffeine ingestion, or a consequence of match interactions (e.g. increased number of tackles; Mullen, Highton & Twist, 2015).

Using a more controlled simulation of rugby league match-play (RLMSP-i, 2 x 23 min bouts), Clarke et al. (2019) had eight professional rugby league forwards consume either a carbohydrate (6.9% carbohydrate-electrolyte, Lucozade Sport) and caffeine (3 $mg \cdot kg^{-1}$) drink (500 ml), or an identical carbohydrate drink without caffeine, 60 min before commencing the RLMSP-i. Improvements in running performance were observed in total distance covered (4374 ± 294 *cf*. 4088 ± 350 m; ES = 0.73), with likely higher (ES = 0.32 – 1.04) increases in high speed running (> 14 $km \cdot h^{-1}$) and average sprint speeds across most playing quartiles after caffeine supplementation. Interestingly, these improvements in external loads were accompanied by likely small to moderate increases in heart rate despite players reporting a likely lower perception of effort. These findings reaffirm performance improvements after caffeine ingestion are largely mediated by a lowered perception of effort, due to caffeine restricting adenosine receptor sites within the CNS, subsequently blocking the inhibitory action of cerebral adenosine (e.g. increased feelings of fatigue; Graham, 2001). The authors concluded that although the effects of caffeine were statistically meaningful on measures of running performance (larger than reported typical error), the RLMSP-i did not reflect the true loads imposed during matches, given that, for example, skilled performances were excluded (e.g. passing).

Similar positive effects of caffeine have been reported during rugby union simulation protocols when ingested at higher doses (4 and 6 $mg \cdot kg^{-1}$, respectively), 60 min before the start of exercise (Roberts et al., 2010; Stuart et al., 2005). Both studies demonstrated improved mean sprint speeds throughout the caffeine compared to placebo trials. Moreover, these improved sprints times were associated with lowered RPE during the caffeine trial (Roberts et al., 2010). Yet, although Stuart et al. (2005) failed to report perceived effort (RPE), these findings were still speculatively attributed to caffeine affecting the CNS, as an adenosine antagonist, leading to a lowered perception of effort. Conversely, caffeinated gum at doses of 400 mg (~3.5 – 4.5

$mg{\cdot}kg^{-1}$), consumed during a simulated half time (15 min), failed to improve subsequent sprint times (40 m) and cognitive function (Stroop task) in fourteen professional academy rugby union players (Russell, Reynolds, Crewther, Cook & Kilduff, 2019). This was despite significantly increasing salivary testosterone (~70%) compared to a placebo trial. This data further ascertains the use of longer periods of time (~60 min) between caffeine ingestion and the onset of exercise, to ensure its ergogenic effects.

2.6.3 Caffeine and Cognitive Function

As well as enhancing several modes of exercise (section 2.6.2), caffeine ingestion can have beneficial effects on cognitive function. Caffeine is known to increase alertness and vigilance (Lorist & Tops, 2003; Zwyghuizen-Doorenbos, Roehrs, Lipschutz, Timms & Roth, 1990), with the most consistent beneficial effects observed during sustained vigilance tasks (i.e. improved visual information processing, improved attention, quicker reaction times and reduced errors; Lieberman, Tharion, Shukitt-Hale, Speckamn & Tulley, 2002; Hogervorst et al., 2008; Smith, 2005). It is suggested that caffeine exerts its effects on cognitive function, in the same manner as physical performance (section 2.6.1), through the blocking of adenosine receptor sites in the CNS (McLellan et al., 2016). Comparable ergogenic effects of caffeine have been reported during cognitive function tests when performed in isolation (Van Duinen, Lorist & Zijdewind, 2005), during (Hogervorst et al., 2008) and after physical tasks (e.g. 1 h cycling time trial; Hogervorst, Riedel, Kovacs, Brouns & Jolles, 1999; Kovacs et al., 1998) in controlled laboratory settings. An area of sport performance whereby caffeine’s ergogenic effects might be more advantageous, are types of exercise whereby concentration, reaction times and technical/tactical skills are associated with successful physical and mental performance - such as rugby league match-play (Hogervorst et al., 2008). Whilst caffeine ingestion is common practice amongst rugby league players (Clarke et al., 2019), limited research exists describing the effect of caffeine on the concomitant technical and physical loads associated with rugby league matches.

2.6.4 Caffeine and Skilled Performance

Caffeine intake (3-6 mg·kg^{-1}) seemingly enhances performance of rugby-related running (Clarke et al., 2019; Stuart et al., 2005; Wellington et al., 2017; Del Coso et al., 2012), yet the effects of caffeine on skilled tasks relating to rugby remain relatively unknown. Stuart et al. (2005) described the effects of caffeine ingestion on both simulated physical and skill demands indicative of rugby union match play. Eleven amateur rugby union players performed a rugby union performance task (for details see section 2.7.2.1), 60 min after consuming either caffeine (6 mg·kg^{-1}) or placebo (dextrose). Briefly, the skilled performance task comprised passing five rugby balls as quickly as possible at a target (1 x 1 m), placed 4 m from the player at a height of 1.5 m (from the ground). Caffeine ingestion resulted in improved passing accuracy (~9.6%). However, given that no data was reported on completion time and the closed nature of performing repeated static passes (to static targets), findings are limited in their application. Conversely, passes during rugby matches are conducted whilst the player is often moving, directed at moving targets (i.e. teammate), under time pressure situations (i.e. before reaching a defending player; Hendricks, Lambert, Masimla & Durandt, 2015).

More recently however, caffeine (6 mg·kg^{-1}) failed to improve performance during a passing accuracy test in nine male amateur rugby union players (Assi & Bottoms, 2014). The skill test involved a reactive agility test (10 m) with a single pass at the end, at a 75 cm target, situated 5 m away (3 x dominant and non-dominant). The authors suggested that caffeine might have less of an effect when the skill involved uses complex cognitive processes required by the skill test. Given the lack of conclusive research describing caffeine's effect on rugby related skill performance, future research should look to determine this using ecologically valid settings, whereby physical and skill demands are experienced together.

2.6.5 Caffeine and Mental Fatigue

A recent review on caffeine's effects on cognitive and physical performance concluded that caffeine may be particularly beneficial during situations that result in impaired cognitive performance (e.g. mental fatigue and sleep deprivation; McLellan et al., 2016). Given the opposing modes of action of caffeine (adenosine antagonist) and fatiguing situations (cerebral adenosine accumulation), it has been suggested that caffeine's neurobiological effects could ameliorate the effect of acute impaired cognitive function (e.g. sleep deprivation and mental fatigue; Goldsteain et al., 2010; McLellan et al., 2016). Accordingly, benefits of caffeine on cognitive function have been observed in sleep deprived (Lierberman et al., 2002; McLellan, Bell & Kamimori, 2004) and mentally fatigued individuals (Van Cutsem et al., 2018). Van Cutsem et al. (2018) reported that response accuracy was significantly improved ($P = 0.017$) in ten healthy male students during a prolonged and demanding cognitive task (90 min Stroop task), after serial caffeine-maltodextrin mouth rinsing (1.2% weight/volume, 0.3 g anhydrous caffeine). The authors postulated that these behavioural changes, resulting from improved cognitive function, were a product of caffeine restoring the dopaminergic transmission within the ACC, subsequently postponing the effects of mental fatigue (Van Cutsem et al., 2018). Accordingly, it is plausible that caffeine's neurobiological effects as an adenosine antagonist could ameliorate the effect of mental fatigue on sports performance. Studies that have shown caffeine administration improves cognitive performance in the presence of mental fatigue support this notion (for a review, see McLellan et al., 2016; Van Cutsem et al., 2018).

To the author's knowledge, only one study has explored the effects of caffeine on exercise performance in the presence of mental fatigue (Azevedo, Silva-Cavalcante, Gualano, Lima-

Silva & Bertuzzi, 2016). This study reported that 5 mg·kg^{-1} caffeine, ingested ~ 90 min before the start of exercise, improved cycling time to exhaustion by ~14% in mentally fatigued (285 ± 42 s) individuals compared to placebo (222 ± 23 s). These findings were accompanied by significantly lower perceived exertion (RPE, ~ 12 – 16 AU) after caffeine consumption (P = 0.048). The authors concluded that these caffeine related improvements in exercise performance in mentally fatigued individuals, provide further evidence for caffeine affecting CNS function. Consequently RPE is reduced, thereby enabling individuals to up-regulate exercise efforts. However, no studies have explored the efficacy of caffeine in mentally fatigued team sport players, or during rugby-related performance.

Given the similarity in mechanisms between mental fatigue and sleep deprivation (i.e. cerebral adenosine accumulation, leading to increased feelings of fatigue and decreased motivation; Martin et al., 2018), it is interesting to note that caffeine enhances rugby passing accuracy in sleep deprived (< 5 h sleep) rugby union players (professional rugby union backs; Cook, Crewther, Kilduff, Drawer & Gaviglio, 2011). The authors of this study observed improvements (P <0.001) in passing accuracy, 90 min after ingesting either 1 or 5 mg·kg^{-1} caffeine capsules, when compared to a placebo trial. Yet, caffeine had no effect on passing performance when players were non-sleep deprived (7 – 9 h sleep), in comparison to a placebo trial. This research supports the notion that caffeine may be more effective as an ergogenic aid during situations of elevated stress (e.g. mental fatigue and sleep deprivation; McLellan et al., 2016). Future research should examine the effects of caffeine during more ecologically valid situations (e.g. similar mental and physical loads experienced during rugby league match play).

2.7 Team Sport Simulation Protocols

Owing to the complexity of - and lack of control during – rugby league match play, simulation protocols based on time motion analysis have been developed to replicate the external and internal loads (physical and physiological) of team sports in a controlled environment. Specifically, large match to match variations in movement demands and the inherent difficulty of measuring useful physiological markers, make establishing meaningful changes in performance problematic. Indeed, between match variability of distance covered high speed running (>14 $km{\cdot}h^{-1}$) is high (CV = ~15%) in team sports, including soccer (Gregson, Drust, Atkinson & Salvo, 2010; Rampinini, Coutts, Castagna, Sassi & Impellizzeri, 2007) and rugby league (Kempton et al., 2014; Waldron et al., 2013).

Traditionally, non-motorised treadmill protocols were devised (generic team sports; Sirotic & Coutts, 2008) based on the time motion analysis of various team sports (Bangsbo, Norregaard & Thorsoe, 1991; Spencer et al., 2004). However, during these simulation protocols, total distance of ~10,000 m were reported (Sirotic & Coutts, 2008), signifying that the application of these simulations to rugby league is limited given whole match and interchanged rugby league players will cover much smaller distances of ~7,000 and ~4,000 m, respectively (Waldron et al., 2011; see section 2.2.1). A further limitation of non-motorised treadmill simulations is the inability to simulate several sport specific movements (e.g. changes of direction and collisions), which have important implications for the physiological load experienced in rugby league (Mullen et al., 2015; Oxendale et al., 2017). Sport specific field-based simulation protocols have since been devised, offering a more ecologically valid alternative to non-motorised treadmill protocols, often incorporating sport-specific movements, such as turning and skilled performances (e.g. passing at targets).

The first recognised field-based simulation was the Loughborough intermittent soccer test (LIST; Nicholas et al., 2000). Briefly, the LIST comprises moving between two cones placed 20 m apart, at varying speeds dictated by an audio signal. The pattern of activity is repeated (part A = walk x 3, sprint x 1, stand 4 s, jog x 3, cruise x 3; part B = jog x 1, cruise x1), lasting ~80-95 min, with players covering between ~7,000 – 11,000 m (Nicholas et al., 2000).

Although the reliability of the LIST is considered sufficient to detect meaningful changes in performance (Nicholas et al., 2000), the validity of this soccer simulation has been questioned due to the limited sport specific actions (e.g. ball interactions) and lower cardiovascular demands (HR) observed compared to soccer match-play (Magalhães et al., 2010). That said, the LIST has been extensively used to determine the efficacy of several nutritional interventions (caffeine; Gant, Ali & Foskett, 2010; carbohydrate; Ali, Williams, Nicholas & Foskett, 2007; carbohydrate and protein; Highton, Twist, Lamb & Nicholas, 2013) on the movement demands indicative of soccer match play.

Since the LIST was first described, simulation protocols have been designed to replicate the internal (physiological) and external (movement) loads associated with several team sports, including soccer (ball sport endurance and sprint test, $BEAST_{90}$; Williams, Abt & Kilding, 2010; Copenhagen soccer test, CST; Bendiksen et al., 2012), rugby union (Bath university rugby shuttle test, BURST; Roberts, Stokes, Weston & Trewartha, 2010; rugby test; Stuart et al., 2005), basketball (basketball exercise simulation test; BEST; Scanlan et al., 2012) and rugby league (rugby league match simulation protocol, RLMSP; Sykes et al., 2013; rugby league movement simulation protocol designed for interchanged players, RLMSP-i; Waldron et al., 2013).

In general, team sport simulations are based on the average movement demands, determined by time motion analysis over several matches. Data pertaining to the average distances covered in distinct speed categories are then used, and often divided into repeated bouts of intermittent activity (e.g. standing, walking, jogging, high speed running and sprinting). The total distance covered or time spent in each speed zones is then divided into equal cycles (moving between various cones covering distances generally covered within that sport, e.g. 10-20 m sprints in soccer; Nicholas et al., 2000), that when performed repeatedly, generally over two repeated bouts with a period of active recovery (e.g. first and second halves), will elicit similar total distances and time spent in each speed zone as those described over the course of a match.

The cycles of activity within team sport simulations are short in duration (~2 - 5 min) and as a consequence are repeated several times over the duration of the protocol (~46 – 100 min). Accordingly, the number of activity cycles repeated throughout the BURST (Roberts et al., 2010), $BEAST_{90}$ (Williams et al., 2010), RLMSP-i (Waldron et al., 2013), LIST (Nicholas et al., 2000) and RLMSP (Sykes et al., 2013) are 16, ~22, 24, ~60 and 80 times, respectively. This method of generating simulation protocols (i.e. repeated cycles of activity) is suggested to be adequate, with several validity studies reporting that simulation protocols elicit similar movement or physiological demands associated with actual match-play (Nicholas et al., 2000; Roberts et al., 2010; Waldron et al., 2013). However, the effects of repeated cycles of activity on the mental load, and associated external and internal load, that participants experience is not well-understood (indeed, the mental demands of simulations relative to games have not been explored). Such repeated cycles might influence performance in several ways, including a 'zoning out', whereby individuals will disengage from the task (e.g. sustained vigilance during a repetitive task) and altered vigilance, which is known to effect decision making performance (Smallwood et al., 2004). As such, the influence of cyclical or random and stochastic protocols on multiple measures or load should be explored.

2.7.1 Rugby League Simulation Protocols

Currently, two rugby league simulation protocols exist based on time-motion analysis, replicating the movement and physiological characteristics of whole match (rugby league match simulation protocol, RLMSP; Sykes et al., 2013) and interchanged players (rugby league movement simulation protocol for interchange players, RLMSP-i; Waldron et al., 2013).

Time motion analysis data (Sykes et al., 2009) based on a multiple-camera system informed the average movement demands during the whole match RLMSP (Sykes et al., 2013). This protocol comprises standing, walking, jogging, running, high-speed running, sprinting and simulated contact (lying prone for 4 s), and reflects the average duration of each locomotive bout observed during a match (Sykes et al., 2013). These locomotive rates are achieved with ~80 repeated cycles of activity, requiring players to move between colored cones at various speeds dictated by audio cues from a CD player. Sykes et al. (2013) reported inter-day reliability CVs of 1.1, 4.2, 10.6 and 2.1% for overall locomotive rates ($m \cdot min^{-1}$), high speed running ($m \cdot min^{-1}$; ~20-25 $km \cdot h^{-1}$), very high speed running ($m \cdot min^{-1}$; >25 $km \cdot h^{-1}$) and average peak sprint velocity, respectively. Although high speed running demonstrated the poorest reliability (CV >10%), this is considered more favorable than the previously reported large match to match variations for high speed running (>15%; Kempton et al., 2014). The authors concluded that both very high intensity locomotive rate (>20 $km \cdot h^{-1}$) and mean peak sprint velocity should be used to assess physical performance when trying to detect small performance changes during the rugby league match simulation protocol (Sykes et al, 2013).

With regards to validity, percentage time spent standing (~5%), walking (~55%), jogging (~30%), running (~6%), high speed running (~3%), sprinting (~0.5%) and contact (~4%) throughout the RLMSP are comparable to those reported during matches (Sykes et al., 2009). As such, the protocol was deemed suitable for investigations in to rugby league performance. In a follow up study, ten male rugby players completed the RLMSP, resulting in elevated markers of fatigue (CK, CMJ, perceived muscle soreness and isokinetic muscle force of the knee flexors and extensors at 60 and 240 $deg \cdot s^{-1}$) at 0, 24 and 48 h after the protocol (Twist & Sykes, 2011). Interestingly, symptoms of exercise-induced muscle damage were still evident up to 48 h after a simulated rugby league match, which is in agreement with changes observed post-match (Twist et al., 2012). That said, the internal loads during the RLMSP (~80% HR_{max})

were lower than those reported during elite rugby league matches (~84% HR_{max}; Waldron et al., 2011). These differences were speculatively attributed to the method of simulating collisions within the RLMSP (i.e. lying in a prone position ~4s), which is considered to be less demanding compared to the greater demands associated with collisions in match-play (Oxendale et al., 2016; Twist et al., 2012).

It is known that the external loads associated with whole match players will differ to players that are interchanged for two briefer (~20 min) and more intense (increased high speed running and number of collisions) playing bouts (Waldron et al., 2013; see section 2.2.1). Given these clear disparities in external loads, time motion analysis conducted by Waldron et al. (2011) was used to produce a protocol that replicates the movement patterns of elite interchanged rugby league players (RLMSP-i; Waldron et al., 2012). The RLMSP-i is similar to the original RLMSP, whereby players perform repeated cycles of activity, moving between colored cones at varying speeds dictated by audio cues from a CD (Waldron et al., 2013). One cycle of the RLMSP-i (~115 s) comprises two distinct components, ball in play (~65 s; e.g. tackling, being tackled, maximal effort sprints and high speed running) and ball out of play (~50 s; walking, jogging and resting), and is repeated 24 times. These cycles are repeated across two shorter bouts (23 min; 12 repeated cycles) with more distance covered using high speed running and a greater number of collisions (~ 27 m.min-1 and ~ 1 tackle every min, respectively). Importantly, this protocol also included the use of a more ecologically valid collision, whereby participants sprinted 8 m before tackling (driving to the floor and rolling 360° whilst grasping the bag) a cylindrical tackle bag (23 kg). Most measures of internal and external loads reported adequate test-retest reliability throughout the RLMSP-i, with CVs <5%, notwithstanding the less favorable reproducibility of high speed running (>14 km.h-1; CV = ~5.5%) and blood lactate concentrations (CV = ~14%). Throughout the RLMSP-i similar external and internal loads to match-play are observed, with 107 - 105 $m \cdot min^{-1}$, 28 – 27 $m \cdot min^{-1}$; 27 – 25 $km \cdot h^{-1}$; 88

– 86%; ~16 AU and 6 -7 mmol·L, reported throughout the first and second bouts for overall locomotive rates, high speed running (>14 km·h^{-1}), peak speeds, %HR$_{peak}$, RPE and blood lactate concentrations, respectively (Waldron et al., 2013; Waldron et al., 2011). Accordingly, the protocol replicates some aspects of rugby league performance in a controlled simulation, allowing detection of altered movement and internal loads due to an intervention. Accordingly, the RLMSP-i has been used to determine the effects of carbohydrate and caffeine ingestion (Clarke et al., 2019), manipulated collisions (Mullen et al., 2015; Norris, Highton & Twist, 2019; Norris, Highton, Hughes & Twist, 2016), manipulated knowledge of task end-point (Highton, Mullen & Twist, 2017) and altered warm up strategies (Fairbank, Highton, & Twist, 2019) on the internal and external loads associated with rugby league competition.

The majority of speeds that participants move at during the RLMSP-i, are dictated by audio commands, meaning that sprints represent one of the few truly self-paced elements of the protocol. Given the importance that pacing has for team sport performance (Waldron & Highton, 2014; Highton et al., 2017b), it is perhaps unsurprising that maximal sprint speeds are more sensitive to interventions compared to, for example, high speed running (Mullen et al., 2015; Highton et al., 2017b; Clarke et al., 2019). The greater reliability for maximal sprint efforts (CV = 2-4%) allows detection of calculated moderate changes (~2%; Waldron et al., 2013).

A limitation of the current RLMSP and RLMSP-i is the lack of skilled actions in the protocols (e.g. ball carrying and passing). Although simulated contacts have been incorporated using a cylindrical tackle bag (Mullen et al., 2015; Waldron et al., 2013), this was originally included to elicit similar physical loads to match play, with no emphasis on the quality of the skill being performed. More recent attempts to improve the validity of the collision in the protocol have, again, focussed on the effect that this action has on internal and external load, rather than the performance in the collision itself (Norris et al., 2019). Although these simulations were initially designed to replicate the movement demands of rugby league match play, the inclusion of measurable skilled actions would allow researchers and practitioners to report the simultaneous effects of interventions on movement and skill relating to rugby league match play. Moreover, the inclusion of skilled actions might increase the external validity of the simulation, and interact with internal and external load as previously discussed (Norris et al., 2019). Indeed, several skill performance tests have been constructed to determine meaningful changes in skilled actions (e.g. passing), during controlled environments. The following section will review the literature describing skilled tests relating to rugby performance.

2.7.2 Simulations of Rugby Related Skill

Tests of rugby-related skill have been developed, whereby meaningful changes can be determined after, for example, training or nutrition interventions. Measurement of skill in rugby have been reviewed in detail elsewhere (see Hendricks et al., 2015), where the authors described the following important considerations when developing tests of sporting skill: how well does the task replicate the specific skilled actions and dynamic environments of match-play (i.e. ecological validity), whether the test can discriminate, for example between playing standards (i.e. construct validity), and if the test re-test variability is small enough to detect meaningful and systematic change (i.e. reliability). An overview of such rugby skill assessments related to the above criteria are discussed below.

2.7.2.1 Rugby Passing

Several aspects of stationary and moving passing ability of rugby players have been assessed. These include measurement of passing accuracy over varying distances (4 – 7 m; Pienaar, Spamer & Steyn, 1998; Assi & Bottoms, 2014; Stuart et al., 2005), maximal passing distance (Pienaar et al., 1998), and quality of passes (Gabbett et al., 2011; Gabbett et al., 2007). Several of these passing tests assess closed skills (i.e. performed in a stable and predictable environment), involving passing at a stationary target (0.6 – 2 m), placed a distance away (4 – 7 m) from a fixed passing zone. The benefits of such tests are that they are practical, reliable and provide objective data (e.g. % accuracy or time to complete the test). However, these skill assessments are often self-paced (Pienaar et al., 1998) which poorly reflect match play, whereby players are required to perform accurate passes in dynamic environments, under significant time pressure (e.g. before being tackled by an opposition player). Consequently, these tests possess limited ecological validity. That said, tests of closed skills have been used to successfully distinguish differences relating to playing standards and positional groups (Spamer, 2009) and determine changes in passing accuracy after nutritional interventions (Assi & Bottoms, 2014; Stuart et al., 2015).

Passing has also been assessed using more open skilled (i.e. players are required to adapt to a dynamic environment) tests (e.g. two attackers vs one defender). Gabbett et al., (2007) developed marking criteria for skilled actions such as passing, whereby expert coaches observe a group of players performing skilled tasks and determine the quality of skill execution, according to pre-determined marking criteria. The benefit of this method of passing assessment is that the skill can be assessed during an ecologically valid scenario within training (e.g. two attackers vs. one defender). Waldron et al. (2012) determined the inter- and intra-observer reliability of expert coaches and novice spectators using the criteria outlined by Gabbett et al. (2007). The intra-tester reliability (percent absolute agreement) was similar for the expert coaches and novice observers for catching (80-85% *cf*. 80 – 85%, respectively) and passing (75 – 90% *cf*. 70 – 85%, respectively). However, the inter-observer (expert *cf*. novice) agreement was poor when assessing the quality of catching (30 – 45%) and passing (50 – 65%) actions. Although greater ecological validity exists during these measures of passing skill, it appears that even when marking criteria are provided a level of subjectivity exists that might introduce measurement error (Waldron et al., 2012).

2.7.2.2 Tackle Technique

Gabbett and colleagues have subsequently developed skill assessment criteria to include a tackle proficiency test using standard marking criteria (Gabbet & Kelly, 2007; Gabbett, 2008). Players performed a one-on-one tackle drill and received one mark for each proficient performance of a technical action (e.g. contacting the target with the shoulder), from a maximum of eight marks. The reliability data suggests acceptable test-retest reliability, with typical error of measurement between 4.7 – 8.2% (Gabbett, 2008). Indeed, the detrimental effects of fatigue on tackle proficiency has since been determined using this measurement tool during a one-on-one tackle drill (Gabbett, 2008). The authors found that most technical actions, according to the set marking criteria, were impaired as a result of fatigue. These impairments were evident for the following criteria: contacting the target in the centre of gravity (ES = 0.4), wrapping arms around the opposition at contact (ES = 1.7) and decreased leg drive on contact with the opposition (ES = 2.3; Gabbett, 2008). Although this method of assessing tackle technique is considered adequately reliable and possesses construct and ecological validity, as with the passing criteria, the measures are subjective, and as such the technical actions are open to interpretation. Moreover, it is anticipated that for more valid and reliable results an expert coach should assess the skilled actions (Gabbett et al., 2007, Gabbett, 2008), raising questions on the application of these tests when expert coaches are not readily available (e.g. during experimental research using amateur players).

Other studies have assessed the skill techniques relating to rugby performance, including reactive agility, kicking, carrying the ball into contact, anticipatory decision making and movement prediction (Hendricks et al., 2015). However, these skilled actions fall outside of the scope of this thesis (for a more comprehensive review see Hendricks et al., 2015). In summary, it appears that the complex and dynamic nature of rugby match-play make fully replicating these environments for the assessment of skill within controlled conditions difficult.

Indeed, Hendricks et al. (2015) propose that varying levels of standardisation, reliability, validity and sensitivity of a test should be considered on a continuum, whereby trade-offs occur (e.g. increased reliability at the expense of ecological validity) depending on the context and specific aims of the skill assessment.

2.8 Conclusions

Most of our understanding of rugby league match load is based upon external load measurements, typically derived from GPS technology (Hausler et al., 2016; Johnston et al., 2014). Players are exposed to significant physical and technical loads, which can be influenced by playing position and fatigue (Kempton et al., 2013; Sirotic et al., 2011). The accompanying internal physiological and perceptual load induced by these external demands also cause prolonged fatigue, which is present up to four days after competition (Twist & Highton, 2013). Increased mental loads (i.e. performing a cognitively demanding task) can manifest in mental fatigue and have adverse effects on subsequent physical, cognitive and technical performance. Our current understanding of mental fatigue and human performance has been summarised in Table 2.1 below.

Table 2.1. Comprehensive list of studies investigating the impact of mental fatigue on human performance (endurance, maximal force production, motor skills and decision making performance). Table adapted from Pageaux and Lepers (2019).

References	Subjects	Mental Fatigue Protocol	Markers of Mental Fatigue	Performance Test				Impact of Mental Fatigue on Performance Test	Perception of Effort During the Performance Test
				Endurance	Maximal Force Production	Motor Skills Test	Sport Related Decision Making Test		
Azevedo et al. (2016)	8 recreationally active males	90 min AX-CPT	↑ in self-reported fatigue	Cycling time to exhaustion at 80% PPO with and without caffeine ingestion	-	-	-	↓ in time to exhaustion without caffeine ingestion, no change in performance with caffeine ingestion	↑
Brownsberger et al. (2013)	8 active males and 4 active cyclists	90 min of a computerised decision-making task	↑ in self-reported fatigue	2 x 10 min cycling at fixed RPE (11 and 15)	-	-	-	↓ in cycling power output at RPE 11 and 15	↑
MacMahon et al. (2014)	18 trained males and 2 trained female runners	90 min AX-CPT	↑ in self-reported fatigue	3 km running time trial	-	-	-	↑ in time to complete the time trial	↑
Marcora et al. (2009)	10 active male and 6 active females	90 min AX-CPT	↑ in self-reported fatigue ↓ in cognitive performance	Cycling time to exhaustion at 80% PPO	-	-	-	↓ in time to exhaustion	↑
Martin et al. (2016)	11 professional male road cyclists and 9 recreational male cyclists	30min of incongruent Stroop task	↑ in self-reported fatigue for both groups	20 min cycling time trial	-	-	-	Reduction in power output in the recreational cyclists group only, no change in performance in the professional cyclist group	↑ in the recreational cyclists group
Otani et al. (2017)	8 active males	90min of different computer-based cognitive tests	↑ in self-reported fatigue	Cycling time to exhaustion at 80% $\dot{V}O_{2max}$	-	-	-	↓ in time to exhaustion	No change
Pageaux et al. (2013)	10 active males	90 min AX-CPT	↑ in self-reported fatigue	20% knee extensors MVC time to exhaustion	Knee extensors MVC	-	-	↓ in time to exhaustion/No change in MVC	↑

Pageaux et al. (2014)	10 recreationally active males	30 min of incongruent Stroop task	No overt mental fatigue	5 km running time trial	-	-	-	↑ in time to complete the time trial	↑
Pageaux et al. (2015)	12 active males	30 min of incongruent Stroop task	↑ in self-reported fatigue	6 min cycling at 80% PPO	Knee extensors MVC	-	-	No measure of performance as all subjects cycles for the same duration/ No change in MVC	↑
Penna et al. (2018)	11 young males and 5 young females (~16 y) swimmers	30 min of incongruent Stroop task	↑ in self-reported fatigue	1500m swimming time trial	-	-	-	↑ in time to complete the time trial	↑
Pires et al. (2018)	8 recreational male cyclists	30 min of Rapid Visual Information Processing test	↓ in cognitive performance	20 km cycling time trial	-	-	-	↑ in time to complete the time trial	↑
Salam et al. (2018)	11 well-trained male cyclists	30 min of incongruent Stroop task	↑ in self-reported fatigue	3 cycling time to exhaustion test at 3 different intensities	-	-	-	↓ in time to exhaustion for all intensities	↑
Smith et al. (2015)	10 recreationally active males	90 min AX-CPT	↑ in self-reported fatigue	45min self-paced intermittent running protocol replicating team sports physical demand	45 min self-paced intermittent running protocol replicating team sports physical demand	-	-	↓ in running velocity at low intensity/ No change in high-intensity and peak running velocities	↑
Smith et al. (2016) *Study One*	12 moderately trained male soccer players	30 min of incongruent Stroop task	↑ in self-reported fatigue	Yo-Yo intermittent recovery test, Level 1	-	-	-	↓ in running distance	↑
Smith et al. (2016) *Study Two*	12 experienced male soccer players	30 min of incongruent Stroop task	↑ in self-reported fatigue	-	-	-	Loughborough Soccer Passing Test and Shooting Test	↑ in penalty time, ↓ in shot speed and accuracy	-
Van Cutsem et al. (2017)	10 trained male cyclists	45 min of incongruent Stroop task	↑ in self-reported fatigue	In a hot environment: 45 min cycling at 60% PPO followed by a cycling time trial	-	-	-	No change in cycling time trial performance	No change
Veness et al. (2017)	12 elite male cricket players	30 min of incongruent Stroop task	↑ in self-reported fatigue	Yo-Yo intermittent recovery test, Level 1	-	Batak Lite hand-eye coordination test	Cricket-run-two test	↓ in running distance/ Trend ↓ in total score/ ↑ in time to complete the test	↑
Vrijkotte et al. (2018)	10 trained male cyclists	90 min of incongruent Stroop task	↑ in self-reported fatigue	Two incremental cycling tests interspaced by the mental fatigue protocol	-	-	-	No difference in peak power output between the two incremental cycling tests	No change
Budini et al. (2014)	12 male (*no information on physical activity*)	100 min of a switch task test	↓ in cognitive performance	-	Knee extensors MVC	-	-	↓ in MVC	-

Duncan et al. (2015)	7 active males and 1 active female	40 min of a vigilance task	Presence of mental fatigue not measured	-	4 x 30 s Wingate test	Coincidence anticipation test	Minnesota Manual Dexterity Turning test	No change in power output/↑ in errors/↑ in time to complete the test	-
Le Mansec et al. (2018)	22 male experienced table tennis players	90 min of AX-CPT	↑ in self-reported fatigue	-	Elbow flexors MVC	-	Table tennis performance test	No change in MVC/↓ in table tennis stroke accuracy and ↓ in ball speed	-
Martin et al. (2015)	7 active males and 5 active females	90 min of AX-CPT	↑ in self-reported fatigue	-	3 min all out cycling test, CMJ, knee extensors MVC	-	-	No change in cycling power output, CMJ parameters and MVC	-
Coutinho et al. (2018)	10 youth male soccer players	30 min incongruent Stroop task	Presence of mental fatigue not measured	-	-	Small-sided game, video analysis of tactical variables	-	Alteration of players positioning on the pitch	-
Head et al. (2016)	11 active males and 7 active females	52 min of a vigilance task	↓ in cognitive performance	-	-	Time on task in body weight resistance training	-	↓ in time on task	-
Head et al. (2017)	20 male infantry male soldiers	49 min of a sustained attention to response task	↓ in cognitive performance	-	-	Marksmanship task	-	↑ in errors (shooting the wrong target) with no change in shooting accuracy	-
Smith et al. (2016)	12 experienced male soccer players	30 min of incongruent Stroop task	↑ in self-reported fatigue	-	-	Soccer-specific decision-making task	-	↓ in accuracy and ↑ in response time	-
Badin et al. (2016)	20 male soccer players	30 min incongruent Stroop Task	↑ in self-reported fatigue	-	-	-	Small-sided game, video analysis of technical variables	↓ in passing accuracy and tackle success	-
Smith et al. (2017)	14 experienced male soccer players	30 min of incongruent Stroop task	↑ in self-reported fatigue	-	-	-	Loughborough Soccer Passing Test	↓ in passing accuracy, no change in movement speeds	-
Rozand et al. (2015)	10 active males	90 min of incongruent Stroop task	↑ in self-reported fatigue	-	-	-	Pointing task with different difficulty level	↑ in movement duration at all difficulty levels	-
Rozand et al. (2015)	6 males and 6 females (*no information on physical activity*)	100 imagined pointing movements (30 min)	↑ in self-reported fatigue	-	-	-	Pointing task	↑ in movement duration	-

MVC=maximal voluntary contraction; PPO=peak power output; RPE=rating of perceived exertion; AX-CPT=AX-continuous performance task. Increased perception of effort was achieved by either; (i) an increased perception of effort (rating) at a fixed workload, or (ii) same perception of effort (rating) with a decreased workload during self-paced exercise.

The extent to which mental fatigue, as a consequence of internal and external loads, is induced by rugby league match-play is currently unknown. Furthermore, the extent to which mental fatigue might alter internal and external loads during rugby league match-play and subsequent physical and technical performance has not been explored. The potential for ergogenic aids, such as caffeine, to abate mental fatigue in rugby are also worthy of investigation.

Available rugby league simulations (Sykes et al., 2013; Waldron et al., 2013) provide a controlled and reliable method of monitoring changes in movement demands relating to rugby league match play. Furthermore, measurements of skill can be incorporated into protocols, providing the sensitivity, reliability and validity have been considered. However, to date no studies have considered the mental demand that simulations place on participants, and whether such demands can be changed to influence internal and external load and performance. The influence of commonly used short repeated cycles of activity in simulations is also worthy of investigation, as this is likely to limit the mental demands of such activity relative to rugby league matches.

Chapter 3

The reliability of a rugby league movement simulation protocol involving stochastic movement patterns

3.1 Introduction

Rugby league movement characteristics vary considerably from match-to-match (e.g. ~15% for high-intensity running; Kempton et al., 2014). Such variation makes it difficult to establish meaningful changes in rugby league performance due to a given intervention. Given the intermittent and stochastic nature of match-play, it is also logistically difficult to obtain physiological and perceptual data during matches, despite this information being valuable when examining the metabolic response to such exercise (Coutts et al., 2003). In an attempt to address these issues, exercise protocols based on time-motion analysis that can be performed in a controlled environment have been devised to replicate the movement and physiological characteristics for both whole match (rugby league movement simulation protocol, RLMSP; Sykes et al, 2013) and interchange players (rugby league movement simulation protocol for interchange players, RLMSP-i; Waldron et al., 2013; Norris et al., 2019).

The reliability (i.e. the test-retest consistency of measurements) of most internal and external load measures taken during available rugby league simulations is sufficient (CV<5%, Sykes et al., 2013; Waldron et al., 2013) to detect meaningful changes that are due to, for example, nutritional or training interventions and not technical error or biological variation (Hopkins, 2000). Indeed, these protocols have been used to detect meaningful changes (6.5–13.4%) in running performance after nutritional supplementation (Clarke et al., 2019), inclusion of physical contacts (Mullen et al., 2015), varying collision types (Norris et al., 2016) and a manipulated knowledge of task end-point (Highton et al., 2017b). Therefore, the use of such simulations to examine changes in elements of rugby league performance offers a viable alternative compared to competitive matches.

Whilst the reliability of existing rugby league simulations has been established, aspects of their validity have been questioned (e.g. method of simulating the tackle, tackle bag or tackle sled; Norris et al., 2016), which has led to studies altering the content of the protocol (e.g. body on body tackle with shield; Norris et al., 2019). A yet unexplored limitation of the existing simulation protocol is the cyclic nature of the movement commands that do not replicate the more stochastic activity associated with actual match-play (Waldron et al., 2013; Waldron et al., 2011). Indeed, the predictable nature of existing simulation protocols might result in a different pacing strategy to that observed in matches (Highton et al., 2017; Waldron & Highton, 2014), where players must regulate their exercise intensity whilst preserving the capacity to perform unpredictable periods of exercise at an intensity greater than the match average (Waldron & Highton, 2014). A more random activity pattern might alter the vigilance required and the 'mental demand' associated with a task (Warm et al., 2008), which is known to have implications for players' perceived exertion (Greig et al., 2007). However, attempts to increase the external validity of simulations might have negative effects on the internal validity and associated reliability. For example, in the study of Norris and colleagues (2019), the improved validity after including a more appropriate contact element seemingly compromised the reliability of measures such as high speed running distance (CV% = 14.4%, Norris et al., 2019) compared to the original simulation (CV% = 5.5%, Waldron et al., 2013).

Establishing the reliability of simulation protocols after the format or content is changed to improve external and internal validity is warranted. Similarly, data pertaining to the reproducibility of associated measures (e.g. subjective task load, cognitive and neuromuscular function) that might be used to assess performance during -and recovery after- any modified

RLMSP-i remain unknown. Therefore, the aim of this study was to assess the test-retest reliability of internal and external measures during a modified simulation of rugby league match-play designed for interchange players (RLMSP-i) performed using a stochastic order of activity. A second aim was to assess the reliability of associated measures of subjective task load, cognitive and neuromuscular function.

3.2 Methods

Participants and Design

Twenty male university rugby players (league and union; age = 21 ± 2 y, body mass = 83.2 ± 9.7 kg, stature = 1.80 ± 0.10 m, predicted maximal oxygen uptake [$\dot{V}O_{2max}$] = 48.9 ± 3.9 ml·kg^{-1}·min^{-1}) completed two trials of a modified (more stochastic) rugby league movement simulation protocol for interchanged players (RLMSP-i; Waldron et al., 2013) in a repeated measures design. After an initial baseline visit to predict $\dot{V}O_{2max}$, participants were familiarised with all experimental procedures. After baseline measurements of body mass, stature and neuromuscular function, participants completed two conditions of the randomised (i.e. less predictable order of activity) RLMSP-i, at a similar time of day (± 2 h), with 7-10 days between trials. The modified protocol comprised the same total number of movement commands as the original RLMSP-i (Waldron et al., 2013); however, the order of events were randomised such that no repeated cycles of activity occurred. Participants were instructed to refrain from strenuous activity, and avoid caffeine and alcohol consumption, in the 24 h before each trial. A self-reported food diary (Appendix 6) for the 48 hours immediately before trial one was completed and replicated in the 48 hours before the remaining trial, to control for effects of pre-exercise dietary intake on performance (Waldron et al., 2013). All participants provided written informed consent and completed a pre-test health questionnaire. Ethics approval for this study was given by the Faculty of Life Sciences Research Ethics Committee (Appendix 1).

Experimental Overview

During the baseline visit, participants performed the multistage fitness test (Brewer Ramsbottom & Williams, 1998) to estimate $\dot{V}O_{2max}$ before being habituated with all experimental procedures. The inclusion criteria required participants to obtain an estimated $\dot{V}O_{2max}$ of >45 $ml \cdot kg^{-1} \cdot min^{-1}$ (>level 9 of the test), to replicate values reported for professional rugby league players (Gabbett, Jenkins & Abernethy, 2011a). Throughout both protocols, movement characteristics using global positioning system (GPS), heart rate (HR) and rating of perceived exertion (RPE) were recorded. Before, at half time and immediately after the protocol reaction time using a Stroop test and blood lactate concentration were measured. In addition, maximum voluntary contraction (MVC) and voluntary activation (VA%) of the quadriceps were measured before and within 14-15 min of completing the protocol. Subjective task load (NASA-TLX; Hart & Staveland, 1988) were also reported ~20 min after completion of the simulation protocol.

Procedures

Baseline Measurements

$\dot{V}O_{2max}$ was estimated using the 20 m multi-stage fitness test (MSFT; Ramsbottom, Brewer, & Williams, 1988). The test consisted of shuttle running at increasing speeds (0.14 $m \cdot s^{-1}$) between two lines of cones 20 m apart until the participant reached volitional exhaustion (Leger & Gadoury, 1989). The maximal heart rate (HR_{max}) achieved during the fitness test was recorded using a HR monitor and watch (Polar Electro OY, Kempele, Finland) and subsequently used to report HR as a percentage of HR_{max} (%HR_{max}) during the simulation. After baseline measures participants were habituated with the testing procedures for Stroop test (2 attempts), subjective task load (NASA-TLX) and isometric dynamometry (4 x MVC with superimposed twitch) before completing one quartile (5.45 min) of the modified RLMSP-i.

Rugby League Movement Simulation Protocol

Participants completed a modified version of a simulation protocol for rugby league match-play (RLMSP-i) designed to replicate the mean movement speeds, distances and playing times of interchanged players (Waldron et al., 2013). Before commencing the protocol, participants performed a standardised 10 min warm-up comprising varied running intensities and dynamic stretches (self-paced jog, high knees, heel flicks and near maximal running). Participants then performed the RLMSP-i on an artificial synthetic grass surface (3G all-weather surface). Environmental temperature and humidity were recorded (THG810, Oregon Scientific Ltd., Berkshire, UK) during each RLMSP-i, and did not differ between trials (pooled data, 14.9 ± 4.3°C and 40.1 ± 7.9%, respectively). Throughout the protocol participants ran alone, following the instruction of an audio signal (CD player) that dictated the speed of movement between various coloured cones. The RLMSP-i lasted 46 min, comprising two 23 min bouts separated by 20 min passive recovery. This replicates the mean time that interchanged players, typically forwards, spend on the pitch during a match (Waldron et al., 2013). The original RLMSP-i comprised 24 repeated cycles of activity (see Waldron et al., 2013), however, throughout the modified protocol (randomised RLMSP-i) the order of events were randomised (but the same for every participant), with no repeated ‘cycles’ of activity. For each quartile of the first and second bout (5.45 min) the movement characteristics were matched throughout the modified protocols. Participants completed the same randomised RLMSP-i (i.e. same order of activity) on two separate occasions. In an attempt to guarantee high and low-intensity actions were not ‘bunched’ in the modified protocol, we ensured that the number and type of each movement were identical for both protocols within each quartile of each bout (i.e. every 5.45 min; Waldron et al., 2013). For example, this resulted in a range of 36.6 to 136 s between 20.5 m sprints in the original simulation (Waldron et al., 2013) and a range of 26.8 to 95.2 s in the modified simulation (for a list of commands throughout the modified simulation see Appendix 7).The match simulation were designed to reproduce total relative running ~100 $m \cdot min^{-1}$, ~1 contact per minute and mean HR response of 85-90% of HR_{max}. An overview of the measurement procedures and order of events before, during and after the RLMSP-i can be found in Figure 3.1.

Movement Demands and Heart Rate

Before performing the RLMSP-i (~10 min), participants were pre-fitted with a custom designed and appropriately sized vest housing a GPS unit (10 Hz MinimaxX S5, firmware 6.75, Catapult Innovations, Melbourne, Australia) between the scapulae. The satellites available and horizontal dilution of precision (HDOP) for all testing visits was 14.4 ± 0.7 (range 13 – 16) and 0.66 ± 0.12 AU (range 0.5 – 1.1), respectively. Previously reported speed zones were utilised for low intensity activity (<14 $km \cdot h^{-1}$) and high speed running (≥14 $km \cdot h^{-1}$; Waldron et al., 2013). Participants' HR was collected throughout performances of the RLMSP-i using a HR monitor (Polar Electro Oy, Kempele, Finland) wirelessly connected to the GPS unit. Data were later downloaded and analysed to determine relative distance covered in total, low intensity activity and high speed running ($m \cdot min^{-1}$), peak speed ($km \cdot h^{-1}$; in each 20.5 m sprint), sprint to contact speed ($km \cdot h^{-1}$; 8 m sprint), PlayerLoad™ (AU) and time spent at high metabolic power >20 $W \cdot kg^{-1}$ (s).

Blood Lactate Concentration

Whole blood was collected and immediately analysed for lactate concentration (Lactate Pro, Arkray, Japan) from a fingertip capillary sample 5 min before and immediately after the first and second bout of the RLMSP-i.

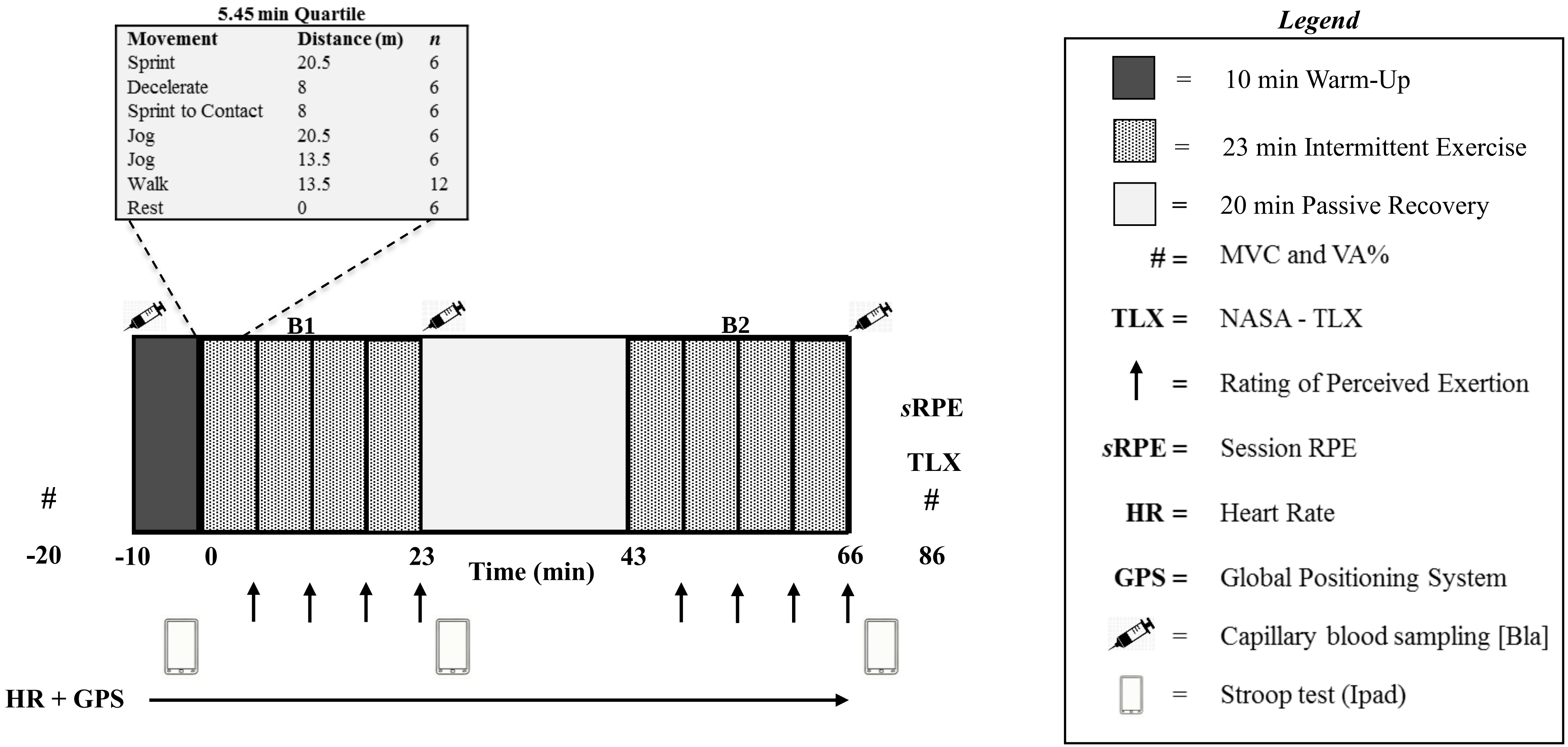

Figure 3.1. Schematic of the rugby league movement simulation protocol, including measurements. B1, bout one; B2, bout two; MVC, maximal voluntary contraction; VA%, voluntary activation determined by interpolated twitch technique; TLX; NASA-Task Load Index; Stroop test, iPad based Stroop test.

Perceptual Measures

Participants' rating of perceived exertion (RPE, 6-20 scale; Borg, 1985) was recorded at the end of every quartile (5.45 min) of the first and second bout during each trial. Session RPE (*s*RPE, 0-10 scale; Foster et al., 2001) was recorded within 20 min of completing each trial.

Neuromuscular Function

Isometric force of the knee extensors in the dominant leg was measured using an isokinetic dynamometer (Biodex 3, Biodex Medical Sytems, Shirley, NY, USA) after a standardised warm up consisting of 5 min cycling at 80 W (no warm up was provided immediately following the simulation). With participants seated in an upright position and 90° flexion in the hip and knee, straps were tightly secured across the thorax and hip to minimise extraneous body movements from the dynamometer (Newman, Jones & Newham, 2003). Participants were then instructed to perform five isokinetic contractions at 60 $deg \cdot s^{-1}$, followed by two isometric contractions at 50, 80 and 100% of their maximum voluntary contraction (MVC). After the warm up, participants performed four MVCs (each 4 s duration) with 2 min rest between efforts (Newman et al., 2003). Strong verbal encouragement was provided and real-time visual feedback on force production was used to encourage maximal efforts (McNair, Depledge, Brettkelly & Stanley, 1996). Force output was A/D converted at a sampling frequency of 1,000 Hz. Signal analysis was conducted using a commercially designed data acquisition software programme (AcqKnowledge III, Biopac Systems, Massachusetts). The highest recorded torque of the four contractions was used for analysis. Transcutaneous electrical stimulation of the quadriceps muscle was delivered using a constant-current stimulator (Digitimer DS7, Hertfordshire, UK) to determine voluntary activation. Two rectangle self-adhesive surface electrodes (5 × 13 cm; Axelgaard Manufacturing Co. Ltd., Lystrup, Denmark) were applied. One electrode was placed distally, 5 cm above the patella covering the vastus lateralis, vastus medialis and rectus femoris muscles. The other electrode was positioned proximally close to the insertion of the quadriceps muscle, avoiding activation of the antagonist (Shield & Zhou, 2004). The skin was prepared by shaving and light abrasion for each electrode site. The outline of both electrodes was drawn on to the skin using a permanent marker to minimise variability of electrode placement between sessions (Keogh, Wilson & Weatherby, 1999). Two paired electrical stimuli (100 Hz) produced by means of square wave impulses (200 Ks) were delivered during a 6 s sampling period. One impulse was delivered to the relaxed muscle pre-contraction (un-potentiated control twitch), after which participants were instructed to contract maximally. The second impulse was delivered 4 s after the control twitch, during the MVC (superimposed twitch). The amperage was optimised for participants during each testing visit by progressively increasing by 25 mA until there was no further increase in peak twitch torque. The amplitude of the superimposed twitch was calculated at 20% above which peak twitch torque was achieved. Voluntary activation (VA%) was later calculated according to the interpolated twitch technique (Merton, 1954), with the ratio of superimposed twitch relative to the twitch response of the relaxed muscle expressed as a percentage (1- [superimposed twitch/control twitch] ×100). Peak MVC was calculated as the mean torque 50 ms before the superimposed stimulation delivery.

Stroop Test

Cognitive function was assessed using a commercially available Stroop test application (EncephalApp Stroop; Bajaj et al., 2013) on a tablet computer (Apple iPad Air 2, California, USA). The test was administered 5 min before and immediately after the first and second bouts of the RLMSP-i. The test required participants to react 80 times as quickly as possible by touching the corresponding colour at the bottom of the screen to various coloured words (red, blue and green) that appeared on the screen. The outcomes of the test were twofold: 1) reaction time (total time in seconds to complete 80 correct reactions) and, 2) accuracy (number of attempts required to complete 80 correct reactions).

Subjective Task Load

Subjective task load was measured ~20 min after each trial of the RLMSP-i, using the National Aeronautics and Space Administration Task Load Index (NASA-TLX; Hart & Staveland, 1988; Appendix 3). Participants rated six subscales of task load (mental demand, physical demand, temporal demand, frustration, effort, and performance), with written definitions of the subscales available throughout (Appendix 3). Each subscale was presented as a 10 cm line with visual anchors at either end (e.g. low/high). Numerical values were not displayed, but the scale ranged from 0-100 AU. Data was recorded to the nearest 5 AU. A weighted scoring of the six subscales was also performed using 15 pairwise comparisons (e.g. mental demand *cf*. effort) between each subscale. Participants were instructed to circle the descriptor that represents the most important contributor to task load during the RLMSP-i. The weighted score corresponds to the number of times each subscale is selected as being the most important contributor to global task load. A task load (weighted rating) score was then calculated by multiplying the weighted score by the rated score for each individual subscale. Finally, a global task load score was then produced by summing the weighted rating for each descriptor, and dividing by the total weights (n=15).

Statistical Analysis

Reliability was determined using the coefficient of variation (CV%) and typical error (TE). The TE was calculated as the standard deviation of the differences between trial one and two divided by $\sqrt{2}$; the CV was then calculated as the TE divided by the grand mean test-retest score, multiplied by 100. The smallest worthwhile change (SWC) in each measure was calculated as 0.2 multiplied by the pooled SD of the repeated trials. The SWC was multiplied by 3, 6, and 10 to determine a moderate (MC), large (LC) and very large change (VLC), respectively (Batterham & Hopkins, 2006; Hopkins, Marshall, Batterham & Hanin, 2009; Hopkins, 2000). These values were then used as ‘analytical goals’ against which the TE could be compared (e.g. a moderate change in a variable for a given sample could be confidently established providing the TE is lower than the MC; Atkinson & Nevill, 1998; Pyne, 2003).

3.3 Results

The only variables to demonstrate a TE lower than the SWC were PlayerLoad^{TM} (AU) during bout 1 and 2 and MVC (N·m) before and after the simulation. All other variables demonstrated a TE at least smaller than the MC. The most reliable measures of external load during the randomised RLMSP-i were noted for relative distance during bout 1 (TE and CV% = 1.6 $m{\cdot}min^{-1}$ and 1.5%, respectively) and bout 2 (TE and CV% = 1.5 $m{\cdot}min^{-1}$ and 1.4%, respectively), average peak speed during bout 1 (TE and CV% = 0.7 $km{\cdot}h^{-1}$ and 2.9%, respectively) and bout 2 (TE and CV% = 0.7 $km{\cdot}h^{-1}$ and 3.0%, respectively), and average PlayerLoad^{TM} during bout 1 (TE and CV% = 5.3 AU and 2.3%, respectively) and bout 2 (TE and CV% = 5.3 AU and 2.3%, respectively). The most reliable measure of internal load, neuromuscular function and perceptual measures before, during and after the simulation were noted for %HR_{max} during bout 1 (TE and CV% = 1.7% and 2.1%, respectively) and bout 2 (TE and CV% = 1.4% and 1.8%, respectively), MVC before (TE and CV% = 14.8 N·m and 4.6%, respectively) and after the simulation (TE and CV% = 10.8 N·m and 3.8%, respectively), and average RPE during bout 1 (TE and CV% = 0.8 AU and 5.5%, respectively) and bout 2 (TE and CV% = 0.5 AU and 3.6%, respectively). All descriptive and reliability data are presented in Tables 3.1 and 3.2.

Table 3.1. Test-retest reliability of external load measures (running intensities, PlayerLoad™ and time at high metabolic power) during the first and second interchange bouts of the modified rugby league movement simulation protocol.

	Distance ($m{\cdot}min^{-1}$)	HSR ($m{\cdot}min^{-1}$)	LSR ($m{\cdot}min^{-1}$)	Peak Speed ($km{\cdot}h^{-1}$)	Peak Speed to Contact ($km{\cdot}h^{-1}$)	PlayerLoad™ (AU)	Time at HMP (s)
Interchange bout 1							
Trial 1 (± SD)	106.4 ± 3.9	30.1 ± 4.9	76.0 ± 4.7	25.2 ± 1.2	13.6 ± 1.1	236.6 ± 29.5	192.7 ± 21.3
Trial 2 (± SD)	105.8 ± 3.8	29.9 ± 5.5	75.6 ± 4.4	23.7 ± 1.4	12.9 ± 1.1	231.9 ± 29.7	186.8 ± 21.4
CV (%)	1.5	6.4	2.6	2.9	2.7	2.3	3.9
TE	1.6	1.9	1.9	0.7	0.3	5.3	7.6
SWC	0.8	1.0	0.9	0.3	0.2	5.8	4.3
MC	2.3	3.1	2.7	0.9	0.7	17.5	12.8
LC	4.6	6.2	5.4	1.8	1.4	35.1	25.5
VLC	7.6	10.3	9.0	3.1	2.3	58.5	42.6
Interchange bout 2							
Trial 1 (± SD)	106.1 ± 3.7	27.5 ± 4.0	78.3 ± 4.3	24.7 ± 1.4	13.4 ± 1.1	235.9 ± 28.1	200.8 ± 23.7
Trial 2 (± SD)	105.5 ± 4.3	27.9 ± 4.4	77.2 ± 4.2	23.4 ± 1.7	12.6 ± 1.1	231.2 ± 28.8	193.5 ± 25.1
CV (%)	1.4	7.1	3.1	3.0	2.4	2.3	4.0
TE	1.5	1.9	2.4	0.7	0.3	5.3	7.8
SWC	0.8	0.8	0.8	0.3	0.2	5.6	4.9
MC	2.4	2.5	2.5	1.0	0.7	16.9	14.6
LC	4.8	4.9	5.1	2.0	1.3	33.8	29.2
VLC	7.9	8.3	8.4	3.3	2.2	56.3	48.6

*HSR = high speed running (> 14 $km{\cdot}h^{-1}$), LSR = low speed running (< 14 $km{\cdot}h^{-1}$), HMP = high metabolic power (>20 $W{\cdot}kg^{-1}$), TE = typical error, CV% = coefficient of variation (%), SWC = smallest worthwhile change, MC = moderate change, LC = large change, VLC = very large change.

Table 3.2. Test-retest reliability of physiological, perceptual, cognitive function and neuromuscular function measures during the first and second interchange bouts of the modified rugby league movement simulation protocol.

	Physiological		**Neuromuscular Function**		**Perceptual**			**Cognitive Function**	
	$\%HR_{max}$	[Bla] (mmol·L^{-1})	MVC (N·m)	VA%	RPE	*s*RPE	NASA-TLX Total	Stroop (s)	Stroop Errors (*n*)
Interchange bout 1									
Trial 1 (± SD)	82.3 ± 4.1	4.9 ± 2.3	318.6 ± 76.3	92.8 ± 4.4	15 ± 1	-	-	73.2 ± 6.5	9.3 ± 1.4
Trial 2 (± SD)	81.5 ± 5.0	4.2 ± 1.8	319.3 ± 84.9	93.7 ± 4.3	14 ± 1	-	-	73.6 ± 7.1	9.2 ± 1.6
CV (%)	2.1	13.4	4.6	1.8	5.5	-	-	3.6	5.9
TE	1.7	0.6	14.8	1.6	0.8	-	-	2.6	0.6
SWC	0.9	0.4	15.7	0.9	0.3	-	-	1.3	0.3
MC	2.7	1.2	47.2	2.6	0.8	-	-	4.0	0.9
LC	5.5	2.5	94.5	5.2	1.6	-	-	8.0	1.7
VLC	9.1	4.1	157.6	8.6	2.6	-	-	13.3	2.9
Interchange bout 2									
Trial 1 (± SD)	82.2 ± 3.9	5.2 ± 2.8	279.0 ± 66.8	86.9 ± 7.4	15 ± 1	7 ± 1	68.3 ± 6.5	74.9 ± 4.3	10.3 ± 2.5
Trial 2 (± SD)	81.2 ± 4.8	4.4 ± 2.3	289.4 ± 78.1	87.6 ± 8.1	14 ± 1	6 ± 2	69.5 ± 15.7	74.1 ± 8.4	9.6 ± 1.8
CV (%)	1.8	19.7	3.8	3.1	3.6	11.4	6.8	3.6	13.6
TE	1.4	1.0	10.8	2.7	0.5	0.7	4.6	2.7	1.3
SWC	0.9	0.5	15.1	1.5	0.3	0.3	2.6	1.3	0.4
MC	2.6	1.5	45.2	4.5	0.8	0.9	7.7	3.9	1.3
LC	5.2	3.0	90.3	9.1	1.6	1.7	15.5	7.8	5.6
VLC	8.7	5.0	150.5	15.1	2.6	2.9	25.8	13.0	4.3

*$\%HR_{max}$ = percentage heart rate maximum, RPE = momentary rating of perceived exertion, *s*RPE = session rating of perceived exertion, [Bla] = blood lactate concentration, NASA-TLX = subjective task load, MD = mental demand, MVC = maximal voluntary contraction, VA% = voluntary activation, TE = typical error, CV% = coefficient of variation (%), SWC = smallest worthwhile change, MC = moderate change, LC = large change, VLC = very large change.

3.4 Discussion

The original rugby league movement simulation for interchanged players was developed to replicate several movement characteristics of elite rugby league match-play in a cyclic manner with acceptable reliability (Waldron et al., 2013). The present study demonstrates that when the order of activity is modified to be more stochastic, the test-retest reliability remains relatively unchanged to that of the original RLMSP-i, with CVs for distance ($m \cdot min^{-1}$) 1.5% *cf.* 1.1%, high speed running (>14 $km \cdot h^{-1}$) 6.4% *cf.* 5.5%, peak speed 2.9% *cf.* 3.9%, $\%HR_{max}$ 2.1% *cf.* 2.0%, for the stochastic and cyclical (Waldron et al., 2013) RLMSP-i, respectively. The CV% is favourably lower in the current study compared to previously reported reliability data describing PlayerLoad ™ (AU; Norris et al., 2019) throughout the first (CV% = 2.3% *cf.* CV% = 4.7%) and second (CV% = 2.3% *cf.* CV% = 5.8%) bouts of the RLMSP-i.

Previous studies reporting the reliability of rugby league simulation protocols have demonstrated the highest variability in movement demands is for high speed running, with CVs of 5.5% (Waldron et al., 2013), 10.6% (Sykes et al., 2013) and 14.4% (Norris et al., 2019) for interchange, whole match and modified simulations, respectively. The data herein show that the inclusion of stochastic movement characteristics has no detrimental effect on the reliability of high speed running during the RLMSP-i. More importantly, the test-retest variability of high speed running (TE = 1.9 $m \cdot min^{-1}$; CV% = 6.4 - 7.1%) is less than previously described changes during the protocol associated with altered nutritional supplementation (-9 $m \cdot min^{-1}$; Clarke et al., 2019), inclusion of physical contacts (-3 $m \cdot min^{-1}$; Mullen et al., 2015) and manipulated knowledge of task end-point (-3.4 $m \cdot min^{-1}$; Highton et al., 2017b). Furthermore, the reliability of the modified simulation compares favourably to the large match-to-match variation in high speed running (randomised RLMSP-i CV% = 6.4% and 7.1% first and second bouts, respectively *cf.* match-play CV% = 20.4% and 23.1% first and second half, respectively; Kempton et al., 2014).

The reliability of average sprint to contact speed has not been described previously, yet this information would be useful when describing altered pacing or fatigue during the protocol due to intervention strategies. Indeed, based on typical changes (~8%) associated with altered contact types during the RLMSP-i (Norris et al., 2016), the current version of the protocol would allow detection of moderate changes in sprint speeds to contact during first (CV% = 2.7%) and second (CV% = 2.4%) bouts. The time spent at HMP has also emerged to describe external loads associated with team sport performance (Oxendale et al., 2017; Gaudino et al., 2014; Kempton et al., 2015), the reliability of which during the RLMSP-i has not been described before. For the first time the test-retest reliability of this novel external load measure during stochastic simulated rugby league movements suggests that HMP is reliable enough to detect moderate changes to performance (CV% = 3.9 - 4.0%) associated with increasing the number of directional changes during an intermittent simulation protocol for example (5.83% increase; Oxendale et al., 2017).

Although less reliable than other measurements, CVs relating to [Bla] were comparable to the original RLMSP-i, with 12.3-16.3% *cf.* 13.4-19.7% for the RLMSP-i and the randomised RLMSP-i, respectively. However, the reliability was sufficient to detect a moderate change in [Bla] (TE = 1.0 mmol·L^{-1}; CV% = 19.7%) associated with changes during the RLMSP-i following manipulated pacing strategies (1.8 – 2.8 mmol·L^{-1} or 38 – 50%; Highton et al., 2017b).

For the first time, this study has explored the test-retest reliability of neuromuscular function after activity that simulates several movement and physiological characteristics of elite rugby league match-play. This reliability allows determination of a ‘real’ change in such measures during the RLMSP-i and are desirable given that reductions in muscle function of ~6.3-7.7% after simulated rugby league (Highton et al., 2017b; Mullen et al., 2015), rugby union (Barber, John, Brown & Hill, 2018) and soccer (Greig, 2008) performance are commonly reported. The reliability for MVC (CV% = 4.6 and 3.8%) and VA% (CV% = 1.8 and 3.1%) before and after the RLMSP-i, respectively, are comparable to previous studies reporting the test-retest reliability after soccer match-play and repeated MVCs (MVC = 2.2 - 4.3%, VA% = 0.7 – 3.4%, respectively; Place, Maffiuletti, Martin & Lepers, 2007; Morton et al., 2005). Not only is the variability of neuromuscular function measures (MVC and VA%) lower than the calculated small and moderate changes, they are also adequately reliable to detect the decrements in MVC (~10 N·m) and VA% (~8%) associated with simulated rugby union match-play performed with and without a tackle (Pointon & Duffield, 2012).

The number of Stroop test errors (CV% = 13.6%) and total subjective task load (CV% = 6.8%) were amongst the least reliable measured variables. Nonetheless, both measures were still able to detect calculated moderate changes. These data provide a baseline for detection of meaningful changes in future research when using the same modified App-based Stroop test after simulated rugby league match-play, with TEs of 2.7 s and 1.3 errors. Furthermore, time taken to complete the Stroop test provides adequate reliability (CV%= 3.6%) to detect changes associated with caffeine supplementation (~6.3%; Soar, Chapman, Lavan, Jansari & Turner, 2016) and sleep deprivation (~30%; Jarraya, Jarraya, Chtourou, Souissi & Chamari, 2013). Future research that uses the NASA-TLX to determine changes in total subjective task load would require a minimum change of 4.6 AU to determine a 'real world' change.

3.4.1 Conclusions and Practical Applications

While insufficiently reliable to detect calculated small changes, these data demonstrate that a stochastic RLMSP-i can detect at least calculated moderate changes in commonly used measures of internal and external load. Furthermore, several internal and external load measures were able to detect previously observed changes during similar exercise protocols. For the first time these data provide a baseline for future research using the randomised RLMSP-i, to determine ‘real world’ changes in Stroop test performance, subjective task load (NASA-TLX) and neuromuscular function (MVC and VA%). Using stochastic rather than cyclic movements during the RLMSP-i therefore has no detrimental effect on its reliability that enables future studies to confidently examine alterations in several perceptual, neuromuscular, internal and external load measures related to rugby league match-play. The effects of stochastic activity during simulated match-play can also be explored.

Chapter 4

Influence of a stochastic vs. cyclical order of events on external and internal load measures during simulated rugby league match-play

4.1 Introduction

The use of team sport match simulation protocols in sports science research is now common. These protocols seek to negate the large variation (~15%) in running distance and intensity observed between matches (Kempton et al., 2014) which might otherwise mask meaningful changes in performance owing to an intervention. Furthermore, physiological and perceptual responses can be measured regularly in a controlled environment, which would not be feasible in competition. Accordingly, in rugby league, various iterations of the rugby league movement simulation protocol (RLMSP) have successfully been used to examine changes in performance (Clarke et al., 2019; Highton et al., 2017b; Norris et al., 2016; Mullen et al., 2015). Indeed, the RLMSP designed for interchange players (RLMSP-i) elicits an internal and external load comparable to those reported during elite rugby league match performance, with similar HR responses (~87 *cf.* ~ 88% HR_{max}), peak running velocities (26.7 *cf.* 26.9 $km \cdot h^{-1}$) and relative low speed distance (~80 *cf.* ~78 $m \cdot min^{-1}$), respectively (Waldron et al., 2013; Chapter 3). However, limitations arise when replicating some aspects of external load, with the protocol producing greater relative high speed (~27 *cf.* ~17 $m \cdot min^{-1}$) and total distance (~107 *cf.* ~95 $m \cdot min^{-1}$) compared to those reported in matches (Waldron et al., 2013; Norris et al., 2016).

One integral aspect of competitive rugby league match-play, which has previously been excluded from simulation protocols, is the stochastic nature of match performance. Indeed, current interchange and whole-match rugby league simulation protocols are comprised of repeated cycles of activity (115 and 130 s cycles, respectively) lasting between 46 and 80 min

(Waldron et al., 2013; Sykes et al., 2013). This inclusion of repeated cycles is common when developing team sport simulation protocols, including simulations of soccer (BEAST90, Williams et al., 2010; LIST, Nicholas et al., 2000; SSP, Stone et al., 2011), rugby union (BURST, Roberts et al., 2010), basketball (BEST, Scanlan et al., 2014) and handball (Thorlund, Michalsik, Madsen & Aagaard, 2008). This approach is likely an attempt to maintain the consistency of performance in such protocols (Waldron et al., 2013). However, preserving high internal validity and associated reliability might compromise the external validity of match simulation protocols (Currell & Jeukendrup, 2008).

When provided with a short habituation (~5 min), the required movement pattern of protocols such as the RLMSP-i are generally learnt, and indeed anticipated before an audio command is provided. The predictable and repetitive nature of current protocols, which is different to the stochastic nature of match-play where accurate decisions based on the information retrieved from a dynamic environment are required, might influence exercise performance and associated physiological and perceptual responses in several ways. For example, with sustained vigilance during a repetitive task, a ‘zoning out’ might occur that results in disengagement from the task (Smallwood et al., 2004). This task disengagement and reduced vigilance can have negative effects on decision making (Smallwood et al., 2004), whilst maintaining vigilance results in a greater ‘mental demand’ associated with a task (Warm et al., 2008). Mentally demanding tasks not only result in mental fatigue after a match (Mashiko et al., 2004) but also have implications for players’ perceived exertion (Greig et al., 2007) and running performance (Smith et al., 2015). Vigilance and associated task engagement might also result in an altered attentional focus (Smallwood et al., 2004). In turn, attentional focus can alter muscle activation (Snyder & Fry, 2012), perceived exertion (Greig et al., 2007) and performance (Marchant, Greig, Bullogh & Hitchen, 2011). Finally, the predictable nature of existing simulation protocols might result in a different pacing strategy being adopted to that observed in matches

(Wadron & Highton, 2014; Highton et al., 2017b), where players must regulate their work rate whilst preserving the capacity to perform *unpredictable* periods of exercise at an intensity significantly greater than the match average (Austin et al., 2011).

Whilst a stochastic simulation is sufficiently reliable (Chapter 3), the effects of a stochastic order of activity during simulated match-play compared to a conventional simulation comprising repeated cycles are currently unknown. It is important to understand the extent to which randomising the required activity, and therefore increasing the requirement for vigilance, might alter the cognitive load experienced when developing match simulation protocols. Therefore, the aim of the study was to investigate the effects of a stochastic order of activity on performance in, and physiological and perceptual responses to, the rugby league movement simulation protocol for interchange players.

4.2 Methods

Participants and Design

Eleven male university rugby players (league and union; age = 21 ± 2 y, body mass = 80.5 ± 6.4 kg, stature = 1.80 ± 0.10 m, predicted maximal oxygen uptake [$\dot{V}O_{2max}$] = 50.8 ± 3.8 $ml \cdot kg^{-1} \cdot min^{-1}$) completed two trials of the rugby league movement simulation protocol for interchanged players (RLMSP-i; Waldron et al., 2013) in a randomised, repeated measures design. After baseline measurements, participants completed a control (CON) and random (RDM) condition of the RLMSP-i, at a similar time of day (± 2 h), with 7-10 days between trials. Participants were instructed to refrain from strenuous activity and avoid caffeine and alcohol consumption in the 24 h before each trial. A self-reported food diary for the 48 hours immediately before trial one was recorded and replicated in the 48 hours before the remaining trial, to control for effects of pre-exercise dietary intake on performance (Waldron et al., 2013).

Pre-exercise urine osmolality did not differ (ES = 0.02; ± 0.71, *unclear*) in the CON (615 ± 292 mOsmol·kg^{-1}) and RDM trial (621 ± 303 mOsmol·kg^{-1}). *Post-hoc* sample size estimation was calculated using the typical error of measurement (0.28) and smallest worthwhile change (0.23 km·h^{-1}) in 20.5 m sprint performance (Hopkins, 2006a); a sample of 10 participants was required. Participants provided written informed consent and completed a pre-test health questionnaire. Ethics approval was gained from the Faculty Research Ethics Committee (Appendix 1).

Procedures

During the baseline visit, participants performed the multistage fitness test to estimate $\dot{V}O_{2max}$ and were habituated with all experimental procedures. The inclusion criteria required participants to obtain a $\dot{V}O_{2max}$ of >45 ml·kg^{-1}·min^{-1} (>level 9 of the test), to replicate physical qualities reported for professional rugby league players (Gabbett et al., 2011). Throughout both protocols, movement characteristics using GPS, HR and RPE were recorded. Before, at half time and immediately after the protocol, the Stroop test reaction time and blood lactate concentration were measured. Maximum voluntary contraction (MVC) and voluntary activation (VA%) of the quadriceps were measured before and within 14-15 min after the protocol. These time delay were inevitable given the distance from the laboratory and playing surface and likely resulted in some restoration in muscle function (e.g. removal of inorganic phosphates and hydrogen ions) between finishing the RLMSP-i and performing the MVC. However, this was accounted for by making this time delay consistent between visits. Subjective task load (NASA-TLX) were reported ~30 min after each simulation protocol (Hart & Staveland, 1988). At similar times before and after the protocol (~30 min), perceived muscle soreness was recorded using a visual analogue scale (VAS; Twist & Eston, 2005). Participants held a squat position (90° at the knee) and rated their quadriceps muscle soreness according to visual anchor points on the scale ranging from 0 (no muscle soreness), 5 (muscle sore on movement) to 10 (muscle too sore to move; Waldron et al., 2013).

For a detailed description of the procedures (*baseline measures, familiarisation procedures, rugby league movement simulation protocol, movement demands and heart rate, blood lactate, perceptual measures, neuromuscular function, Stroop test (~3 min) and subjective task load*) see Chapter 3 section 2 and for the reliability of the reported measures see Chapter 3 section 3.

Rugby League Movement Simulation Protocol

Environmental temperature and humidity were recorded (THG810, Oregon Scientific Ltd., Berkshire, UK) during each RLMSP-i, and did not differ between trials (pooled data, 12.3 ± 2.7°C and 37.5 ± 9.1%, respectively). Near nude body mass was recorded immediately before and after the RLMSP-i using balance beam scales (Seca, 712, Hamburg, Germany) and fluid intake was recorded to estimate fluid loss induced by exercise and did not differ between trials (pooled data, -0.19 ± 0.35%; percent change in body mass including fluid intake). The CON trial comprised 24 repeated cycles of activity (see Waldron et al., 2013). For each quartile of the first and second bout (5.45 min) the movement characteristics were matched between the two protocols. However, throughout the RDM protocol the order of events were randomised, with no repeated 'cycles' of activity. Both match simulations were designed to reproduce total relative running ~100 $m \cdot min^{-1}$, ~1 contact per minute and mean HR response of 85-90% of HR_{max}. The number of each movement and distances covered during one quartile of the simulation (5.45 min) is reported in Table 4.1, which was identical for both simulations (RDM and CON).

Table 4.1. Movement commands and distance covered during one quartile period (5.45 min) of the standard and stochastic RLMSP-i.

Movement	***n***	**Distance (m)**	**Cumulative Distance (m)**
Sprint	6	20.5	123
Decelerate	6	8	48
Sprint to Contact	6	8	48
Jog	6	20.5	123
Jog	6	13.5	81
Walk	12	13.5	162
Rest	6	0	0
Total	**-**	-	585

Statistical Analysis

Changes in dependent variables were analysed using magnitude-based inferences. Effect sizes were calculated as the difference between trial means divided by the pooled standard deviation and supplemented with qualitative descriptors of the mechanistic effect. The magnitude of the observed change between conditions were calculated as the between-participant standard deviation (*sd*) x 0.2, 0.6 and 1.2 for a small, moderate and large effect, respectively (Hopkins et al., 2009). Previously established thresholds for the probabilities of a substantial effect based on the 90% confidence limits were utilised, they were: < 0.5% *most unlikely*, 0.5–5% *very unlikely*, 5–25% *unlikely*, 25–75% *possibly*, 75–95% *likely*, 95–99.5% *very likely*, > 99.5% *most likely* (Hopkins, 2006b). Effects with confidence limits across both a *likely small* (≥5%) positive and negative change were classified as *unclear*. All calculations were completed using a predesigned spreadsheet (Hopkins, 2006b). Data are presented as means ± SD and effect sizes (ES) ± 90% confidence intervals (CI).

4.3 Results

Movement demands

Relative distance was greater during the RDM trial over the entire simulation (ES = 0.26; ± 0.35; *possible small* increase). Unclear differences were observed in low intensity distance, high intensity distance, sprint to contact speed, PlayerLoad™ and time spent at high metabolic power between trials (see Table 4.2). Movement variables across each quartile of the first and second bout are presented in Figure 4.1. Differences between trials for relative distance, high speed running and sprint to contact speed across the protocol was generally *unclear* (Figure 4.1; A, B and C). However, for the mean sprint speed (Figure 4.1; D) there was a *likely* and *very likely moderate* increase in the RDM trial compared to the CON across all quartiles of the protocol.

Table 4.2. Total relative distance, low intensity activity (<14 $km{\cdot}h^{-1}$), high intensity running (≥14 $km{\cdot}h^{-1}$), mean sprint speed, PlayerLoad™ and time at high metabolic power for control and random trials during the whole simulation. Mean ± SD, effect size (± 90% CI), and qualitative descriptor for comparison.

	Trial		**ES (90% CI)**	**Qualitative Descriptor**
	CON	**RDM**		
Total ($m{\cdot}min^{-1}$)	104.0 ± 5.1	105.5 ± 4.0	0.26 (0.35)	*Possibly small* ↑
Low ($m{\cdot}min^{-1}$)	77.0 ± 3.9	77.8 ± 3.8	0.19 (0.65)	*Unclear*
High ($m{\cdot}min^{-1}$)	26.7 ± 4.9	27.7 ± 4.3	0.19 (0.55)	*Unclear*
Sprint to Contact ($km{\cdot}h^{-1}$)	13.2 ± 1.4	13.5 ± 1.1	0.17 (0.39)	*Unclear*
Sprint Speed ($km{\cdot}h^{-1}$)	21.6 ± 1.6	22.5 ± 1.4	0.50 (0.45)	*Likely moderate* ↑
PlayerLoad™ (AU)	459 ± 52	450 ± 47	0.17 (0.44)	*Unclear*
Time at HMP (s)	246 ± 40.2	252 ± 48	0.11 (0.51)	*Unclear*

Total = total distance covered per minute; Low = low intensity activity, <14 $km{\cdot}h^{-1}$; High = distance covered high speed running, ≥ 14 $km{\cdot}h^{-1}$ per minute; Sprint to Contact = maximum speed achieved during the 8 m sprint to contact; Sprint Speed = maximum speed during the 20 m sprint; Time at HMP = time spent at metabolic power >20 $W{\cdot}kg^{-1}$.

Physiological and Perceptual Measures

Unclear differences were observed between trials in $\%HR_{max}$ across the entire protocol (ES = 0.15; ± 0.31; *unclear*). Blood lactate concentration was similar between trials before the protocol. After the first and second bout, blood lactate concentration increased less after the

RDM compared to the CON trial (*likely small* and *possible small* decrease, respectively). Body mass, corrected for fluid intake, decreased following the CON (1.3 ± 0.71 %) and RDM (1.0 ± 0.21 %) with no difference between trials (ES = 0.25; ± 0.34; *unclear*). Participants reported higher average momentary RPE and *s*RPE after the RDM protocol. There were unclear differences in perceived muscle soreness between trials (see Table 4.3).

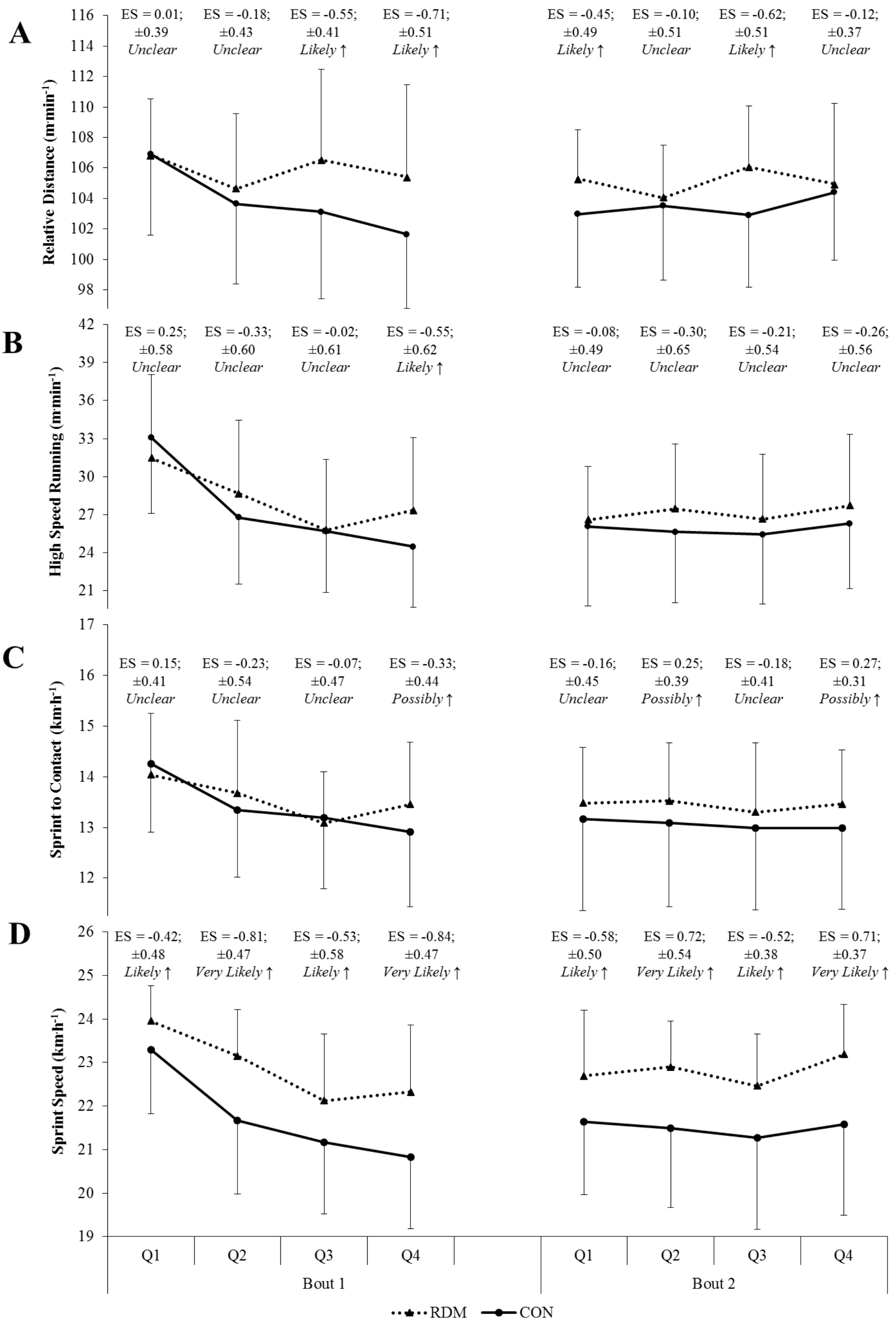

Figure 4.1. Movement variables during each quartile (Q) of the first and second bout of the match-simulation protocol, mean ± SD, ES; ±90% CI), and qualitative descriptor for comparison between trials. High Speed Running = ≥14 km·h^{-1}; Sprint to Contact = 8 m sprint to contact; Q = quartile (5.45 min). **A**: relative distance. **B**: high speed running. **C**: sprint to contact speed (8 m). **D**: sprint speed (20.5 m).

Table 4.3. Percentage heart rate peak, blood lactate concentration, rating of perceived exertion and session rating of perceived exertion for control and random trials, Mean ± SD, effect size (± 90% CI), and qualitative descriptor for comparison.

	Trial		**ES (90% CI)**	**Qualitative Descriptor**
	CON	**RDM**		
%HR_{max}	83.1 ± 7.2	81.9 ± 3.9	0.15 (0.31)	*Unclear*
[Bla] (mmol·l^{-1})				
- Pre	2.5 ± 1.1	2.6 ± 0.7	0.10 (0.52)	*Unclear*
- Mid	6.0 ± 2.5	4.9 ± 1.9	0.40 (0.32)	*Likely small* ↓
- Post	5.9 ± 2.7	5.1 ± 5.9	0.28 (0.32)	*Possibly small* ↓
RPE	13.0 ± 1.4	14.3 ± 1.0	0.87 (0.54)	*Very likely moderate* ↑
*s*RPE	5.5 ± 1.8	6.5 ± 1.3	0.52 (0.49)	*Likely moderate* ↑
Perceived Muscle Soreness				
- Pre	1.3 ± 1.6	1.3 ± 1.1	0.00 (0.67)	*Unclear*
- Post	3.2 ± 2.2	3.4 ± 2.0	0.11 (0.51)	*Unclear*

%HR_{max} = percentage of heart rate maximum; [Bla] = blood lactate concentration; RPE = rating of perceived exertion; sRPE = session rating of perceived exertion.

Muscle Function

The reduction in isometric knee-extensor torque after exercise was *most likely small* (-14.6 ± 5.2%, ES = 0.56; ±0.20) and *very likely small* (-12.4 ± 6.2%, ES = 0.48; ±0.24) for the CON and RDM, respectively (Figure 4.2). Between trials, the change in knee extensor peak torque was *unclear* after the simulation protocol (CON =282.7 ± 80.7 N·m, RDM =279.0 ± 66.7 N·m; ES = 0.04; ±0.16). Voluntary activation (VA%) *very likely* (*moderate*) decreased after exercise in both the CON (-8.3 ± 4.8%) and RDM (-6.0 ± 4.1%) protocols (ES = 0.95; ± 0.55; ES = 1.23; ± 0.84, respectively; Figure 4.2).

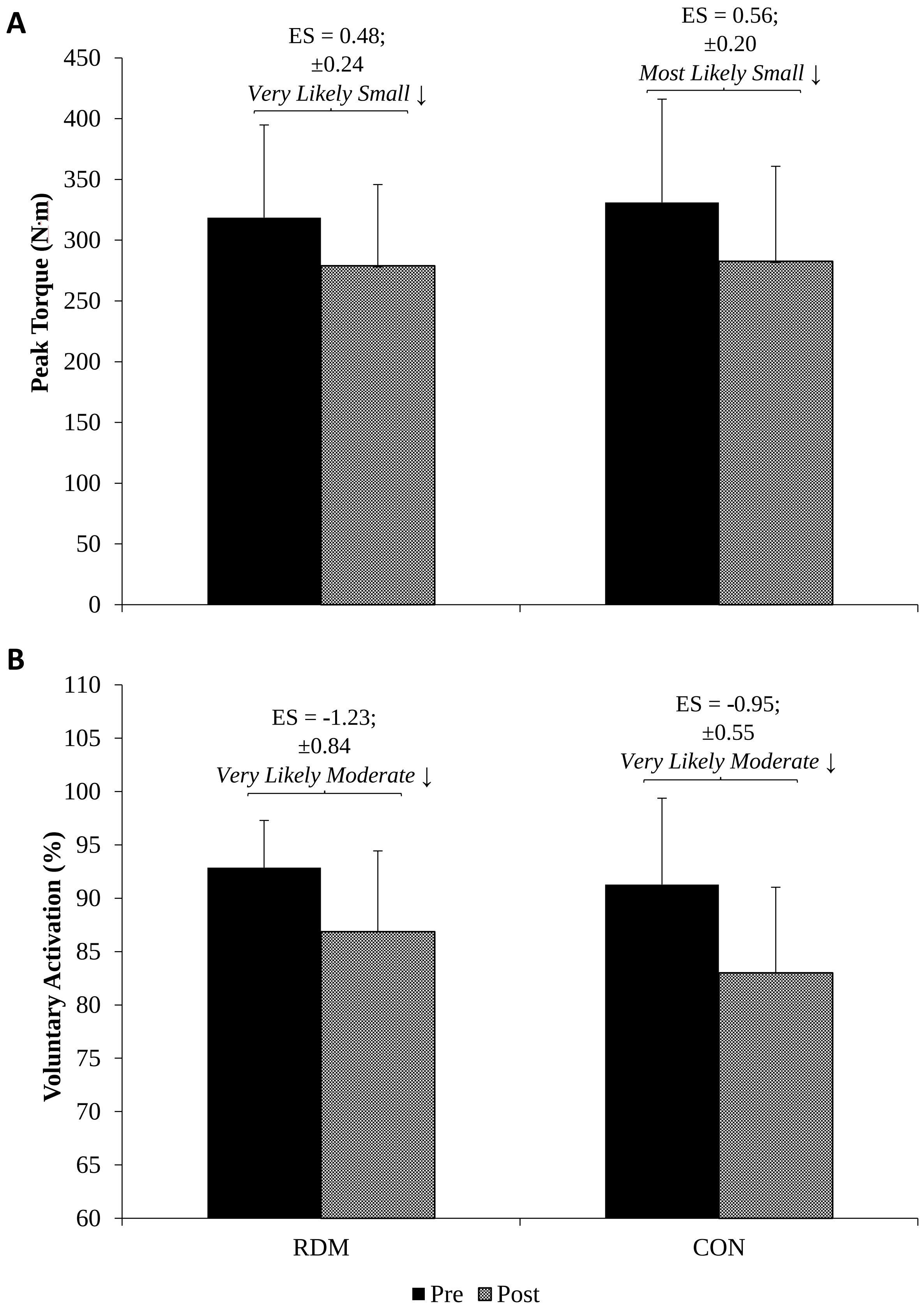

Figure 4.2. Peak torque (A) and percentage voluntary activation (B) of the dominant knee extensors following the rugby league movement simulation protocol.

Stroop Test

Time taken to complete the Stroop test was greatest (ES = 0.59; ± 0.50; *likely small* increase) after the RDM (75.0 ± 4.3 s) compared to the CON trial (72.2 ± 4.3 s). Similarly, the total number of attempts required to complete the task increased (ES = 0.65; ± 0.67; *likely small* increase) after the RDM (10.3 ± 2.5) compared to the CON trial (9.3 ± 1.4; Table 4.4).

Table 4.4. Reaction time and accuracy during the Stroop test for control and random trials, Mean ± SD, effect size (± 90% CI), and qualitative descriptor for comparison.

	Trial		**ES (90% CI)**	**Qualitative Descriptor**
	CON	**RDM**		
ST - Time (s)				
Pre	75.6 ± 5.3	76.9 ± 5.8	0.21 (0.57)	*Unclear*
Mid	73.6 ± 7.3	73.2 ± 6.5	0.06 (0.40)	*Unclear*
Post	72.2 ± 4.3	75.0 ± 4.3	0.59 (0.50)	*Likely small* ↑
Total	221.5 ± 15.1	225.1 ± 14.5	0.22 (0.40)	*Possibly small* ↑
ST - Attempts (*n*)				
Pre	9.5 ± 1.6	10.4 ± 3.2	0.51 (0.62)	*Likely small* ↑
Mid	9.7 ± 2.0	9.3 ± 1.3	0.21 (0.46)	*Unclear*
Post	9.3 ± 1.4	10.3 ± 2.5	0.65 (0.67)	*Likely small* ↑
Total	28.5 ± 4.4	29.9 ± 6.5	0.30 (0.44)	*Possibly small* ↑

ST-time = Stroop test reaction time; ST-attempts = Stroop test number of attempts.

Subjective Task Load

Total task load score was *possibly (small)* higher (ES = 0.25; ± 0.31) in the RDM (67 ± 10 AU) compared to the CON trial (62 ± 19 AU). Differences in task load subscales were *unclear* between trials, with the exception of mental demand with a *likely small* increase in the RDM trial (ES = 0.56; ± 0.57; Figure 4.2).

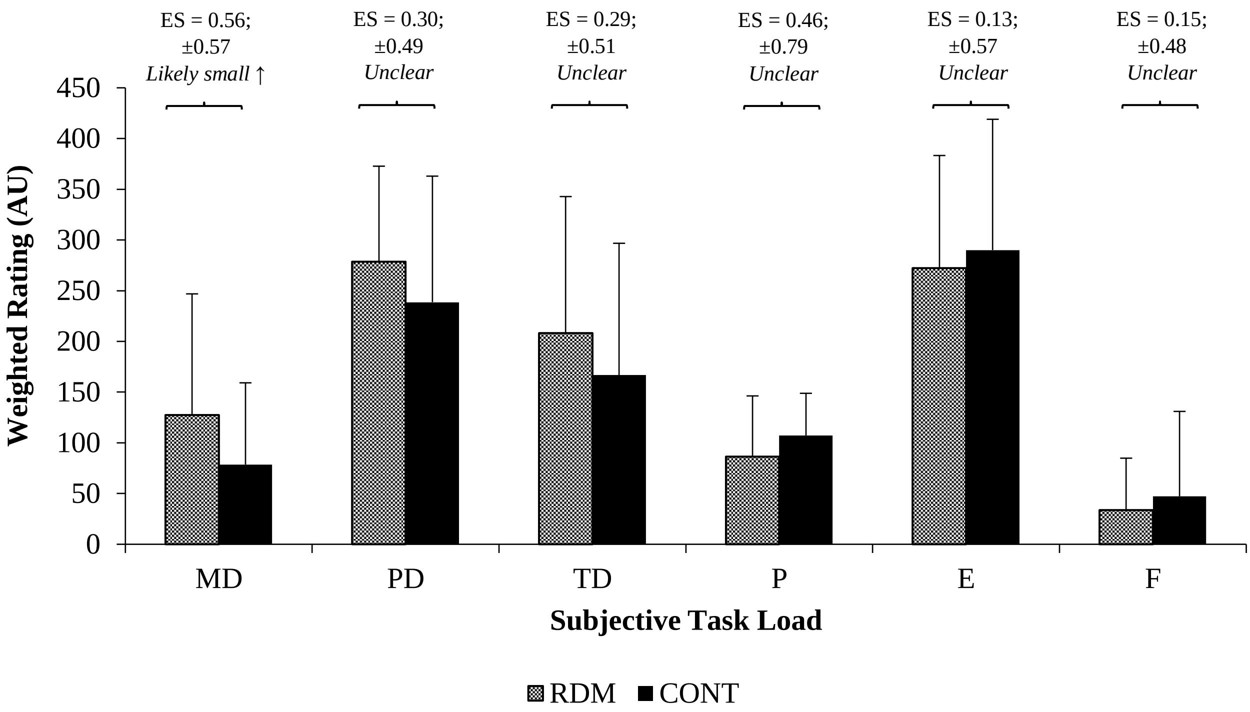

Figure 4.3. NASA-Task Load Index weighted rating of the six subscales (MD, mental demand; PD, physical demand; TD, temporal demand; P, performance; E, effort; F, frustration). Mean ± SD, ES; ± 90% CI, and qualitative descriptor for comparison between trials.

4.4 Discussion

This study examined the running, physiological and perceptual responses to performing a simulated rugby league match with either a cyclical or stochastic order of events. Small increases in total distance, peak speed, RPE, *s*RPE, reaction time, task errors, overall rating of task load and mental demand were observed when the RDM simulation was completed. Changes in total low speed activity, high speed running, peak speed when sprinting to contact, HR, perceived muscle soreness, MVC and VA% over the course of the protocols were *small* and similar between trials.

This is the first study to manipulate and quantify the mental demands associated with simulated rugby activity. The data shows that having more random and unpredictable movement commands than those traditionally used in team sport simulations increases how mentally demanding the exercise is perceived to be. This is in agreement with observations that repetitive (Manly, Robertson, Galloway & Hawkins, 1999) and learnable actions (Van der Linden, Frese & Meijman, 2003) that require less vigilance (Warm et al., 2008) require fewer attentional resources and result in lower mental fatigue. As such, it is proposed that the stochastic and unpredictable order of events employed in the RDM trial increased vigilance requirements for participants to respond correctly to the upcoming instruction. Indeed, greater mental demands have been reported when uncertainty of a signal's origin is increased (Warm, Dember & Hancock, 1996), which results in a greater 'vigilance decrement' (i.e. a decrement in information processing and resulting cognitive performance). The observation here that Stroop test performance was *possibly* poorer in the RDM trial (increase in time and attempts; 3.6 s and 1.4, respectively) would support such findings. Moreover, these reported decrements in Stroop performance were greater than the observed typical error described in Chapter 3 (time and attempts; TE = 2.6-2.7 s and 0.6-1.3, respectively). Future studies should explore whether cognitive function that more closely replicates match-like actions (e.g. decision making for skill execution) is similarly influenced by the degree of mental demand associated with simulated match activity.

RPE is thought to be a key determinant of performance and fatigue in team sports such as rugby (Highton et al., 2017b; Waldron & Highton, 2014). The aforementioned higher mental demand potentially explains the observed increase in state and session RPE in the RDM trial. Indeed, the observed increase in RPE (Table 4.3) were greater than the typical error established in Chapter 3 (TE = 0.7 and 0.8 AU, RPE and *s*RPE, respectively), suggesting that these changes are likely due to intervention and not a result of measurement error (Hopkins, 2000). RPE is informed by numerous afferent and efferent factors (Nethery, 2002; McLaren et al., 2017), including the cognitive demands of a task (Bray, Graham, Ginis & Hicks, 2012). Indeed, McLaren et al. (2017) recently demonstrated that cognitive RPE explained a significant proportion of variance in session RPE reported during rugby conditioning sessions. However, other studies have reported no difference in RPE when performing a mentally demanding task during exercise (Mehta & Agnew, 2011; Mehta & Agnew, 2012); additional explanations for the observed increase in RPE are therefore warranted.

It is possible that the greater vigilance required to correctly respond to the commands in the RDM trial resulted in participants adopting a greater associative attentional focus (i.e. participants' attention was directed toward pertinent information associated with completing the RLMSP-i, such as sprinting to the correct cone; Smallwood et al., 2004). If true, this could explain the higher RPE and increased sprint performance in the RDM trial. Task association can increase RPE relative to task dissociation (Baden, McLean, Tucker, Noakes & Gibson, 2005; Hutchinson & Tenenbaum, 2007), due to a greater internal focal awareness of physiological sensations. Furthermore, task association, particularly when it is external (where attention is focussed on completing the outcome of the task rather than the bodily movements required and associated physiological responses), has been shown to enhance performance across a variety of exercise tasks, such as maximal force production, vertical jumping, sprinting and endurance exercise (for a review, see Wulf, 2013).

Indeed, the monotony of the control condition (i.e. repeated cycles of activity) better replicates the typical procedures used to induce mental fatigue, such as prolonged Stroop tasks (Smith et al., 2016). Despite reporting greater mental demand in the randomised condition, the improved performance (i.e. sprint and cognitive function) might be a result of the unpredictable order alleviating the mental demand, which is supported by the increased effort and frustration (albeit it unclear) in the control condition. Although speculative, these findings suggest that the repeated cyclical order of activity might have altered performance as much as the inclusion of less predictable movement patterns.

Afferent feedback from multiple physiological systems is thought to influence RPE (Hampson et al., 2001), and both heart rate and [Bla] are related to athletes' RPE during small-sided games (Coutts, Rampinini, Marcora, Castagna & Impellizzeri, 2009). In the present study, %HR_{max} was not different between trials, and is therefore unlikely to have resulted in a higher RPE. Furthermore, the *likely* lower [Bla] in the RDM trial might be expected to have resulted in a lower RPE. However, it should be noted the reliability of [Bla] measured during the RLMSPi is poor (CV% = 13.4 – 19.7%; Chapter 3). It is also well established that work performed immediately before sampling influences blood lactate concentrations (Bangsbo et al., 1991). After the final maximal intensity effort (20 m maximal sprint and 8 m sprint to contact), there was a period of 1.11 min and 0.26 min until the end of the protocol for CON and RDM, respectively. Given that participants seemingly have an increased external load during RDM (i.e. sprinting faster and covering more distance), the higher blood lactate concentration during CON is likely to reflect the movement activity before sampling rather than an overall increase in exercise intensity (which might increase in RPE).

For the first time, this study assessed changes in MVC and VA% after a simulated rugby league match. The percent decrease in MVC and VA% response was similar following the RDM (12 and 7%, respectively) and CON (14 and 9%, respectively) trials. These decrements in neuromuscular function are greater than the reliability measured after the RLMSP-i (CV% = 3.8 - 3.1%; MVC and VA%, respectively; Chapter 3). Moreover, the MVC response is comparable to the mean values reported for rugby league players immediately (8 ± 11%) and two hours after competitive match-play (12 ± 13%; Duffield et al., 2012). However, Duffield et al. (2012) reported no difference in VA% when comparing baseline (90.1 ± 6.7%) to immediately (-0.4%) and two hours (-0.8%) after match-play. These disparities in VA% reported following match-play (Duffield et al., 2012) and simulated rugby league match-play might be due to differences in methodology, such as stimulation site (e.g. neural *cf.* muscle;

Shield & Zhou, 2004) stimulation frequency (e.g. singlet cf. doublet; Shield & Zhou, 2004), exercise intensity (relative distance; 75 $m \cdot min^{-1}$ *cf*. 104 $m \cdot min^{-1}$; Thomas et al., 2015) and training status (average MVC; 214 $N \cdot m$ *cf*. 330 $N \cdot m$; Stackhouse et al., 2001). The observed decrement in VA% in RDM (-6.5%; ES = 0.48) and CON (-9.1%; ES = 0.56) trials of the RLMSP-i when compared to baseline (92.9 ± 4.5% and 91.3 ± 8.1%, respectively), suggest reductions in force generating capacity of the knee extensors after movements replicating rugby league match-play are attributed to both central (e.g. decreased neural drive and muscle recruitment) and peripheral (e.g. substrate depletion, hydrogen ion accumulation, and potassium imbalance) mechanisms (Rampinini et al., 2011; Howatson & Milak, 2009; Brownstein et al., 2017).

The similar neuromuscular response to both conditions is consistent with previous research reporting no difference in MVC and VA% after periods of mental exertion (Rozand, Pageaux, Marcora, Papaxanthis & Lepers, 2014). Unlike the negative effects of mental fatigue on endurance performance (Marcora et al., 2009) and self-paced exercise (Brownsberger et al., 2013), mental fatigue seemingly does not impair maximal force production over a short duration (Rozand et al., 2014). This could go some way to explaining why the stochastic protocol resulted in greater maximal sprints, in spite of the small but meaningful increase in mental demand and impaired cognitive function.

Interestingly, in each trial, assessment of subjective task load demonstrated higher ratings for subscales of physical demand, temporal demand and effort compared to the relatively smaller contribution to overall task load of mental demand, performance and frustration (Figure 4.3). Whilst the physiological and performance demands of rugby and other team sports are well documented (Coutts et al., 2003; Cummins et al., 2013; Gabbett, 2005; Johnston et al., 2014; Waldron et al., 2011), surprisingly little information exists on the mental demands of match-play. As such, this data cannot be compared to that from matches. Mashiko et al. (2004) reported greater mental fatigue immediately after university rugby union match-play, with elevated Profile of Moods State (POMS) scores for anger, confusion, depression, fatigue and total mood disturbance. This is not surprising given the requirement for prolonged concentration and vigilance during matches (Gabbett & Benton, 2009). Given that, studies should seek to further explore the mental demand associated with performance and physical demands of match-play to allow more specific training and accurate simulation of match performance.

The findings of this study have numerous practical application. Firstly, when team sport simulation protocols are designed it should be noted that physiological, perceptual and performance responses can be influenced by the order of events that are performed. Such differences might have important implications for the validity of team sports protocols. Moreover, repetitive movement patterns, which require less vigilance, might reduce repeated sprint performance in team sports protocols. These findings might also be important for training practices in rugby league, as the environment (e.g. stochastic order) in which a drill is performed could seemingly manipulate self-paced sprint performance, which might lead to an altered training response if performed chronically. Whether such an effect results in different adaptive responses to exercise with training, as is the case with attentional focus and resistance training (Schoenfeld et al., 2018), warrants further investigation. Finally, these findings also have implications for those seeking to replicate the movement and mental demands of match-play in training situations and promote the use of practices that employ random rather than repetitive movements, e.g. small-sided games.

Potential Limitations

The present study has several limitations that should be acknowledged. Firstly, the proposed mechanism of the RDM trial being affected by task association is speculative and would have benefited from a direct attempt to assess attentional focus. However, these methods are often associated with numerous threats to validity (Brick, MacIntyre & Campbell, 2014). As a consequence of changing the order of events in RDM, it is possible that sprint speed was influenced by preceding actions so that some sprints might have been potentiated (Bevan et al., 2010) or impaired by fatigue (Waldron et al., 2013). However, this is not the most likely explanation of altered sprints, as average sprint performance were used for analysis and the number of sprints were the same across each five minute period. In addition, attempts were made to ensure that the number, type and relative spacing of demanding activities – such as sprinting - were as well-matched between protocols as feasible (Appendix 7). Whilst these attempts would negate the possible effects of potentiated sprints, it cannot be discounted that the activity performed immediately before and after demanding activities influenced their outcome. Finally, although the current RLMSP-i provides a simulation for several movement demands of rugby league match-play, there are numerous limitations regarding the ecological validity of this test as it fails to account for several other elements of match-play including skill performance (e.g. catching, passing, kicking, tackling).

4.4.1 Conclusions

Manipulating the order of events during the RLMSP-i to be more stochastic can alter the mental demand associated with simulated match-play, potentially due to a greater external associative attentional focus during the task, which in turn can improve self-paced sprint performance, impair decision making capacity and increase perceived exertion. Accordingly, when simulating match play, the cognitive demand and vigilance requirement associated with the task should be considered. Investigations into the mental demands of competitive rugby league match-play are needed, such that valid training and research replications of match demands can be made.

Chapter 5

Influence of contextual factors, performance indicators and movement demands on the subjective task load associated with professional rugby league match-play.

5.1 Introduction

Rugby league match demands have been well reported due to advances in technology and a growing interest in monitoring the 'load' that an athlete undergoes during training (Lovell et al., 2013), match-play (Waldron et al., 2011; Hausler et al., 2016), or both (Twist et al., 2017). While much of the research and current applied practice in rugby league measures external loads derived from micro-technology (GPS and accelerometers; e.g. Waldron et al., 2011, McLellan et al., 2011b), these measures simply describe the activity that a player has completed and might not accurately reflect the physiological or perceptual demands imposed on the individual (Fox, Stanton, Sargent, Wintour & Scanlan, 2018). Internal loads are adopted as a method of quantifying the response (physiological and perceptual) to these external loads, with session rating of perceived effort (*s*RPE) traditionally used to determine the perceived exercise intensity associated with rugby league training (Lovell et al., 2013) and match-play (Johnston et al., 2013; McLean et al., 2010; Waldron et al., 2011). Perception of effort is considered a valid, non-invasive and inexpensive measurement tool for internal load (Foster et al., 2001). Indeed, perception of effort is informed by both the external and internal (physiological) loads in rugby league players, with total distance, distance covered high speed running (>14 $km \cdot h^{-1}$), $\%HR_{peak}$ and collisions (collisions/min) correlated with changes in RPE (Lovell et al., 2013; Waldron et al., 2011).

The widespread quantification of exercise intensity using session RPE (*s*RPE) combined with exercise duration (i.e. *s*RPE-TL), is considered a global measure of internal load (Lovell et al., 2013; Waldron et al., 2011). Although *s*RPE-TL can provide a global measure of internal load, it might oversimplify the multifactorial psychophysiological construct of match-play (Weston et al., 2015). The use of differential RPE (*d*RPE) has also been suggested as a method to quantify and discriminate the internal loads associated with rugby training, including individual session ratings for breathlessness, upper/lower body muscle exertion and cognitive demands (McLaren et al., 2017). McLaren et al. (2017) concluded that *d*RPE represent different dimensions of perceived exertion, thus providing a more detailed quantification of the internal loads experienced by players, beyond solely reporting *s*RPE. However, it might be argued that this reductionist method of gaining one (*s*RPE) or several (*d*RPE) ratings of internal load might lack the sensitivity to measure unique loads associated with rugby training and competition (e.g. collision; Lambert & Borresen, 2010). Large individual variability also exists, given that numerous sources of load (external and internal) are present that are largely dictated by playing position and the actions required of that position (McLaren et al., 2017; Weston et al., 2015).

Numerous factors contribute to the workload (i.e. the cost of performing a task on the individual; Hart, 2006) of team sport performance. Indeed, the dynamic psychophysiological demands experienced by players are constructed from the task demands (e.g. external demands of match-play), the contextual factors under which the task is performed (e.g. playing home or away), and the skills, behaviour and perceptions of that individual (DiDomenico & Nussbaum, 2008). Although the external demands of match-play are well documented, and the effects of several contextual factors on movement demands have been explored (e.g. opposition quality alters the amount of high speed running; Kempton & Coutts, 2016), to the author's knowledge there is no research describing the effect contextual factors might have on a players subjective task load during match-play. Such information on the subjective task load of matches (i.e. how the workloads experienced are perceived by the individual) would be useful when prescribing training that acts to simulate not only movement and physiological demands, but also to elicit a particular construct of subjective task load (e.g. mental demand). Furthermore, information pertaining to the subjective task load of matches could support the development of more ecologically valid match simulation protocols than those that currently only replicate selected internal (physiological response) and external (movement demands) loads of match-play (e.g. RLMSP-i; Waldron et al., 2013), with little regard of the contextual factors, skill requirements and subjective task load associated with match performance. Indeed, in Chapter 4 mental demand was altered by the inclusion of some elements of rugby league match-play (stochastic movement patterns), with subsequent effects on running performance during a simulation of rugby league match-play. Further studies are therefore warranted to examine the subjective task load associated with actual match-play.

Contextual, performance and movement demands vary from one match to another (Kempton et al., 2014). In an attempt to assess the independent effects of multiple factors whilst controlling for several other variables, multilevel linear mixed modelling has been adopted to report the effects of various factors on the match demands (internal and external loads; Kempton & Coutts, 2016; Delaney, Thornton, Duthie, & Danscombe, 2016; Dalton-Barron et al., 2018). Using this method, several internal (*s*RPE; Dalton-Barron et al., 2018) and external (GPS; Delaney et al., 2016) loads can be correlated with contextual (e.g. winning and losing), technical (e.g. tackles made) and temporal (e.g. playing duration) factors relating to rugby performance. Relationships exist between several contextual factors and movement demands; for example, playing against lower quality opposition is associated with an increase in high speed running distance (Kempton & Coutts, 2015). However, no studies have used this approach to examine the subjective task load associated with rugby league match performance. Therefore, the aims of this study were twofold: (i) to describe the subjective task load of rugby league match-play using the NASA task load index and (ii), to determine their association with several contextual match factors, technical performance and external movement demands using multilevel linear mixed modelling.

5.2 Methods

Study Design

A longitudinal observational study design was used to examine the effect of selected contextual factors, performance and movement demands on elite rugby league players' subjective task load index, quantified by the National Aeronautics and Space Administration Task Load Index (NASA-TLX; Hart & Staveland, 1988) and session rating of perceived exertion (*s*RPE; Foster et al., 2001). Individual subjective task load was collected from professional rugby league players from one club competing in the European Super League throughout the 2017 season (February – September). Data were collected during match-play (global positioning system, performance analysis and contextual data) and during the subsequent 'recovery session' the day after each match (subjective task load and perception of effort) at the same time of day (9:00 – 11:00 am).

Participants and Contextual Data

With ethics approval from the Faculty of Medicine, Dentistry and Life Sciences Ethics Committee (Appendix 2) and written informed consent from the club, 29 professional rugby league players (age = 26 ± 4 years; body mass= 94 ± 10 kg; stature= 182 ± 6 cm) from the same club competing in the European Super League were recruited for the study. Players were categorised according to playing positions as adjustables (half-back, hooker, stand-off and loose forward, *n*=8), outside backs (fullback, winger, centre, *n*=11) and hit-up forwards (prop and second row, *n*=10). The inclusion criteria required players to have entered the field of play during a competitive match and to attend a recovery session at the club's training ground 13-15 hours after the match. As such, individual data were excluded when players were unable to attend the recovery session the day after a match (*n*=18), due to concussion (*n*=8), musculoskeletal injury (*n*=3) or non-injury related reasons (*n*=7). Whole match data were excluded when a recovery session was not provided within 24 hours after the match (*n*=4). Therefore, data were collected from 26 matches (Super League, *n*=19; Super 8s, *n*=7), involving 29 players, culminating in 441 individual data sets. Throughout the competitive season, 16 matches were won, 13 were lost, with one draw resulting with an average points difference of 145 and a final league position of 4th. Match data were subcategorised according to season phase, early (September - April; *n*=9), mid (April - July; *n*=10) and late (July - September; *n*=7). Opposition quality was determined as 'high' (*n*=11) or 'low' (*n*=15), depending on league position at the end of the competitive season using a median split. Data were reported on 13 home and 13 away fixtures. Matches took place on Thursday and Friday evenings (8:00 pm; *n*=22), with the remaining fixtures on Saturday and Sunday afternoons (3:00 pm; *n*=4).

Procedures

Movement Demands

The players were habituated with the GPS devices, as movement characteristics were routinely collected during training and matches. Players were pre-fitted with a playing jersey that housed the 10 Hz GPS unit (Viper pod, STATSports Belfast, UK) between the scapulae. GPS units were activated before the pre-match warm-up (~40 min before kick-off). The same units were worn by players for each match to avoid inter-unit variation. Information on GPS signal strength and quality was unavailable. Data were 'split' live by the same individual into playing halves and individual interchange bouts during the match. Previously reported speed zones were used for low intensity activity (<14 $km \cdot h^{-1}$) and high speed running (≥14 $km \cdot h^{-1}$; Waldron et al., 2013). Data were later downloaded and analysed using STATSports software (Viper PSA software, STATSports, Belfast, UK), to calculate relative distance covered in total, low intensity activity and high speed running ($m \cdot min^{-1}$), number of sprints, sprint distance (distance covered >20 $km \cdot h^{-1}$), accelerations (total), decelerations (total) and time spent at high metabolic power >20 $W \cdot kg^{-1}$ (s).

Technical Demands

Performance analysis using video footage of each match was conducted by Opta Sports (Opta Sportsdata Limited, Leeds, UK) and later analysed with permission. The analyses was conducted by Opta and provided to the Super League club. Data were reported on several key performance indicators as suggested by the coaching staff at the club, including; number of passes, tackles, missed tackles, carries, metres and errors made during each match (for operational definitions see Appendix 8).

Subjective Task Load and Perceptual Measures

Subjective task load was measured 13-15 hours after each match during the team recovery session at the club's training ground, using the National Aeronautics and Space Administration Task Load Index (NASA-TLX; Hart & Staveland, 1988). This time course was determined from the lack of access with players immediately following the match and to allow consistency between matches (i.e. the data was always collected at the same location and similar time of day). Players were instructed to reflect on the entire time spent "on-field" during the match-played the day before and to complete the pen and paper version of the NASA-TLX without consulting teammates. Players rated six subscales of task load (mental demand, physical demand, temporal demand, frustration, effort, and performance), with written definitions of the subscales available throughout (Appendix 3). Procedural details for measuring subjective task load are described in detail elsewhere (Chapter 3 section 2). During the same recovery session and immediately before completing the NASA-TLX, players were required to report session RPE (*s*RPE, 0-10 scale; Foster et al., 2001) relating to the match.

Statistical Analyses

Eight separate two-level linear mixed models were constructed to determine the influence of skill performance, contextual factors and movement demands performed during match-play on each dependant variable (six subscales of the NASA-TLX; weighted rating, total subjective task load and *s*RPE; Table 5.1). Individual players were included as random factors. When creating the model (Table 5.1) a "step-up" approach was employed starting with an "unconditional" null-model, whereby only the level 2 random factors (player) were included (West, Welch & Galecki, 2014). Subsequently, each level 1 fixed effect (covariate) was introduced to the model and retained if the model was significantly altered ($P<0.05$) as determined by the maximum likelihood ratio and χ^2 statistic. As the intercept, derived from the convergence of all random slopes (individual players), resulted in a height of $x = 0$, and none of the continuous fixed factors were measured at 0 (e.g. 0 m distance), the data was mean centred to shift the origin of the intercept. The *t*-statistic, from the final model, was converted to an effect size correlation (η^2) with 90% confidence intervals (90% CI; Rosnow, Rosenthal & Rubin, 2000). The likelihood of the observed effect was determined using a pre-designed spreadsheet (Hopkins, 2002) and considered according to the quantitative chances of a true effect with following qualitative descriptors; *almost certainly not* (<1%), *very unlikely* (1-5%), *unlikely* (5-25%), *possibly* (25-75%), *likely* (75-97.5%), *very likely* (97.5-99%), *almost certainly* (>99%; Hopkins et al., 2009). Effect size correlations were interpreted as < 0.1, *trivial*; 0.1-0.3, *small*; 0.3-0.5, *moderate*; 0.5-0.7, *large*; 0.7-0.9, *very large*; 0.90-0.99, *almost perfect*; 1.0, *perfect* (Hopkins et al., 2009). Statistical packages for social sciences (SPSS, version 24; SPSS Inc., Chicago, IL, USA) was used to construct the linear mixed models.

Table 5.1. Technical performance analysis, contextual and movement demand covariates included in the models.

Level of data	Variable	Data	Classification
Level 2 *(random factor)*	Player		
Level 1			
(*dependant variables*)	*NASA – Subjective Task Load Index*		
	Total	Continuous	
	Mental Demand	Continuous	
	Physical Demand	Continuous	
	Temporal Demand	Continuous	
	Performance	Continuous	
	Effort	Continuous	
	Frustration	Continuous	
	*s*RPE	Continuous	
Covariates (*fixed factors*)	Tackles	Continuous	*n*
	Carries	Continuous	*n*
	Errors	Continuous	*n*
	Position	Dummy	OB, A, HUF
	Opposition quality	Dummy	High, low
	Season phase	Dummy	Early, mid, late
	Match location	Dummy	Home, away
	Match Outcome	Dummy	Win, lost
	*s*RPE	Continuous	Arbitrary unit
	Total time	Continuous	min
	Interchanges	Continuous	*n*
	Distance per min	Continuous	$m{\cdot}min^{-1}$
	Accelerations	Continuous	*n*
	Decelerations	Continuous	*n*
	Sprints	Continuous	*n*
	Sprint distance	Continuous	m
	High metabolic power	Continuous	Time (s)

5.3 Results

Positional comparisons of the performance analysis (Table 5.2), temporal and movement demands (Table 5.3) were averaged and described for contextual purposes.

Table 5.2. Descriptive technical performance analysis match data between positional groups (data reported as number per match; Mean ± SD).

	Adjustables (n = 127)	Outside backs (n = 130)	Hit-up forwards (n = 184)	Average
Passes	40 ± 37	5 ± 5	3 ± 4	14 ± 26
Tackles	26 ± 14	9 ± 7	25 ± 8	21 ± 13
Carries	7 ± 4	13 ± 4	12 ± 5	11 ± 5
Errors	1 ± 1	1 ± 1	1 ± 1	1 ± 1
Penalties	1 ± 1	0 ± 1	1 ± 1	1 ± 1

Table 5.3. Time played, number of interchanges and movement demand match data between positional groups (Mean ± SD).

	Adjustables (n = 127)	Outside backs (n = 130)	Hit-up forwards (n = 184)	Average
Time played (min)	73 ± 24	91 ± 8	54 ± 19	70 ± 24
Interchanges (n)	1 ± 1	0 ± 0	2 ± 1	1 ± 1
Distance (m)	6735 ± 2214	7792 ± 919	4707 ± 1597	6184 ± 2116
Distance ($m \cdot min^{-1}$)	91 ± 5	85 ± 6	86 ± 5	87 ± 6
Accelerations (n)	520 ± 185	551 ± 71	362 ± 117	462 ± 156
Decelerations (n)	503 ± 179	513 ± 70	349 ± 109	441 ± 147
Sprints (n)	13 ± 6	25 ± 6	11 ± 7	16 ± 9
Sprint distance (m)	238 ± 117	482 ± 135	195 ± 132	291 ± 178
Time at HMP (s)	480 ± 180	480 ± 60	300 ± 120	420 ± 120

As shown in Figure 5.1, average data for the NASA-TLX revealed relatively greater weighted ratings for the subscales of effort and physical demand compared to mental demand, temporal demand, performance and frustration.

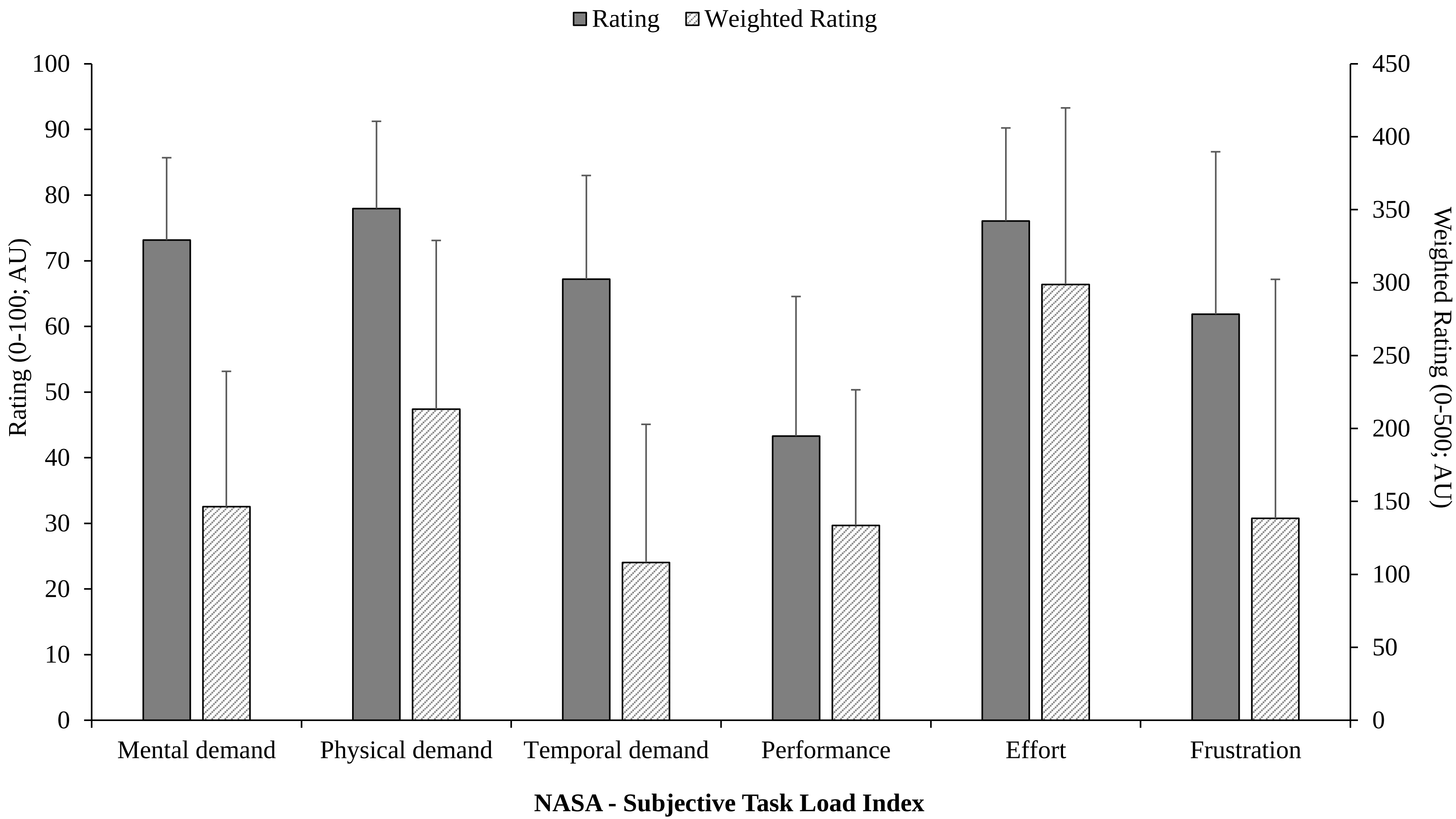

Figure 5.1. Average NASA-Task Load Index rating and weighted rating for the six subscales (MD, mental demand; PD, physical demand; TD, temporal demand; P, performance; E, effort; F, frustration). Mean ± SD.

All independent variables included in the final model for subjective **mental demand** (match outcome, time played and number of accelerations) were *unclear*, excluding a *likely small* correlation with the number of errors (η^2 = 0.10; Figure 5.2). Defensive tackling efforts (η^2 = 0.19) resulted in *very likely small* increases in subjective **physical demand** (Figure 5.2). *Most likely small* increases were also observed in subjective physical demand after matches that were won (η^2 = 0.21), with increased *s*RPE (η^2 = 0.34) and with greater time spent at high metabolic power (>20 W·kg; η^2 = 0.16). Time spent on the field during matches resulted in a *likely small* increase in subjective **temporal demand** (η^2 = 0.11), with hit-up forwards reporting a *very likely small* decrease in temporal demand compared to adjustables (η^2 = 0.21). Players reported **performance** as being better (lower rating = better performance) with *very likely small* decreases in subjective performance when matches where won (η^2 = -0.12) and perception of effort was higher (η^2 = -0.13). **Effort** was *most likely* higher when matches were won (*small*; η^2 = 0.28), playing against higher quality opposition (*small*; η^2 = 0.19) and when players perception of effort was higher (*moderate*; η^2 = 0.38). Players performing more interchange bouts reported a small but *very likely* increase in temporal demand (η^2 = 0.13, Figure 5.2). Winning matches (*moderate*; η^2 = -0.48) and increased *s*RPE (*small*; η^2 = -0.21) resulted in a *most likely* decrease in subjective **frustration**. Conversely, an increase in the number of errors during the match resulted in a *very likely small* increase in frustration (η^2 = 0.15; Figure 5.2).
Greater number of tackles (η^2 = 0.18), errors (η^2 = 0.15) decelerations (η^2 = 0.12) and increased sprint distance (η^2 = 0.13) during matches resulted in *very likely small* increases in **total workload** (Figure 5.3). Losing matches (η^2 = 0.36) and increased perception of effort (η^2 = 0.27) lead to *most likely moderate* and *small* increases in total workload, respectively. Conversely, fewer carries (η^2 = -0.18) and accelerations (η^2 = -0.14) during match-play was associated with a *most likely* and *very likely small* increase in total subjective workload, respectively. Finally, greater number of tackles (η^2 = 0.24), carries (η^2 = 0.11), increased time spent on the field (η^2 = 0.27) and when players covered more relative distance (η^2 = 0.15) meant *very likely* and *most likely small* increases in ***s*RPE** (Figure 5.3).

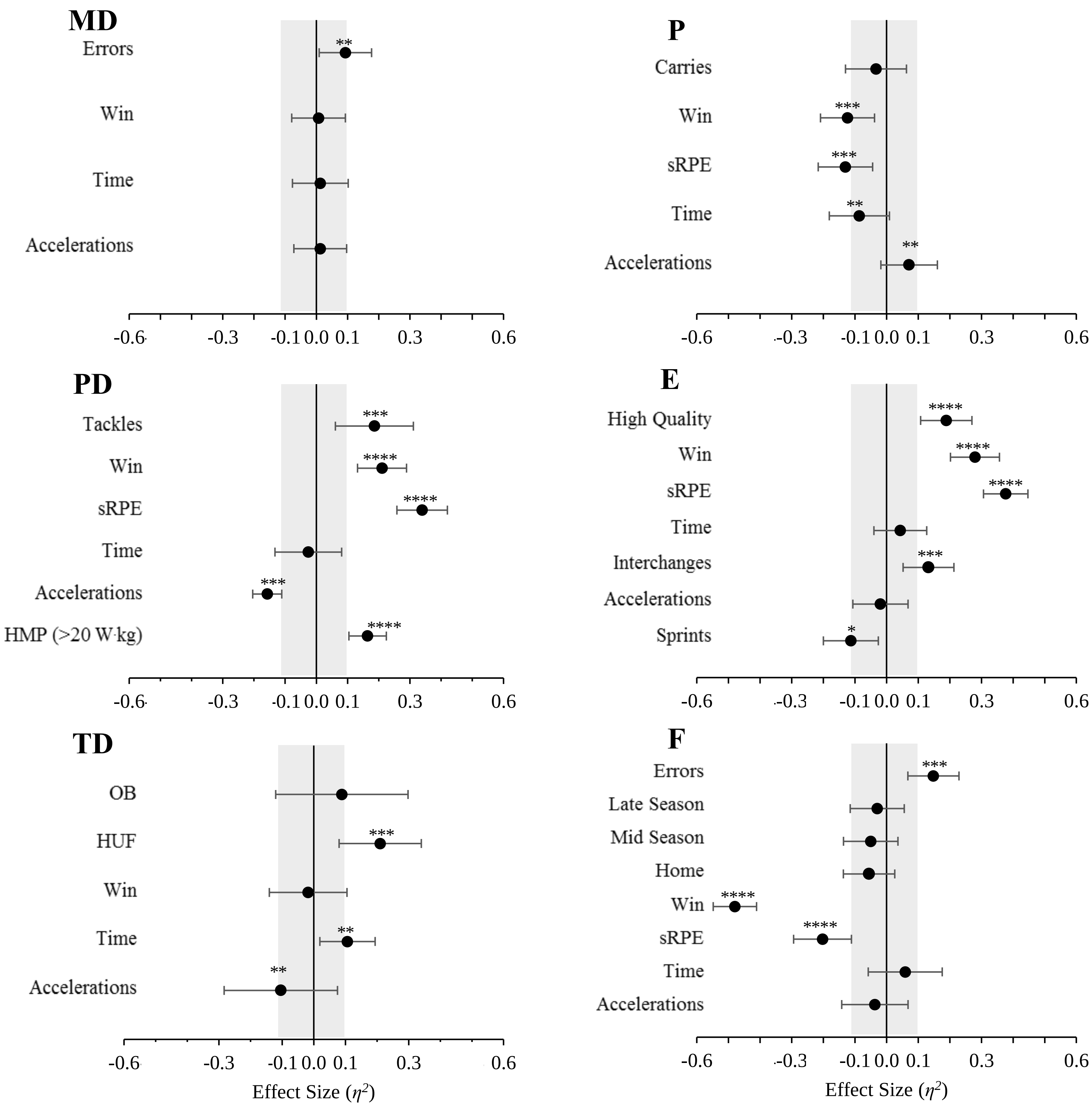

Figure 5.2. Standardised effects (effect size correlation; η^2, ± 90% confidence intervals) of individual, contextual, internal and external load measures on the six subscales of the NASA-TLX (weighted rating). *=*possibly*, **=*likely*, ***=*very likely*, ****=*most likely*. MD= mental demand, PD= physical demand, TD= temporal demand, P= performance, E= effort, F= frustration. HMP= high metabolic power (s).

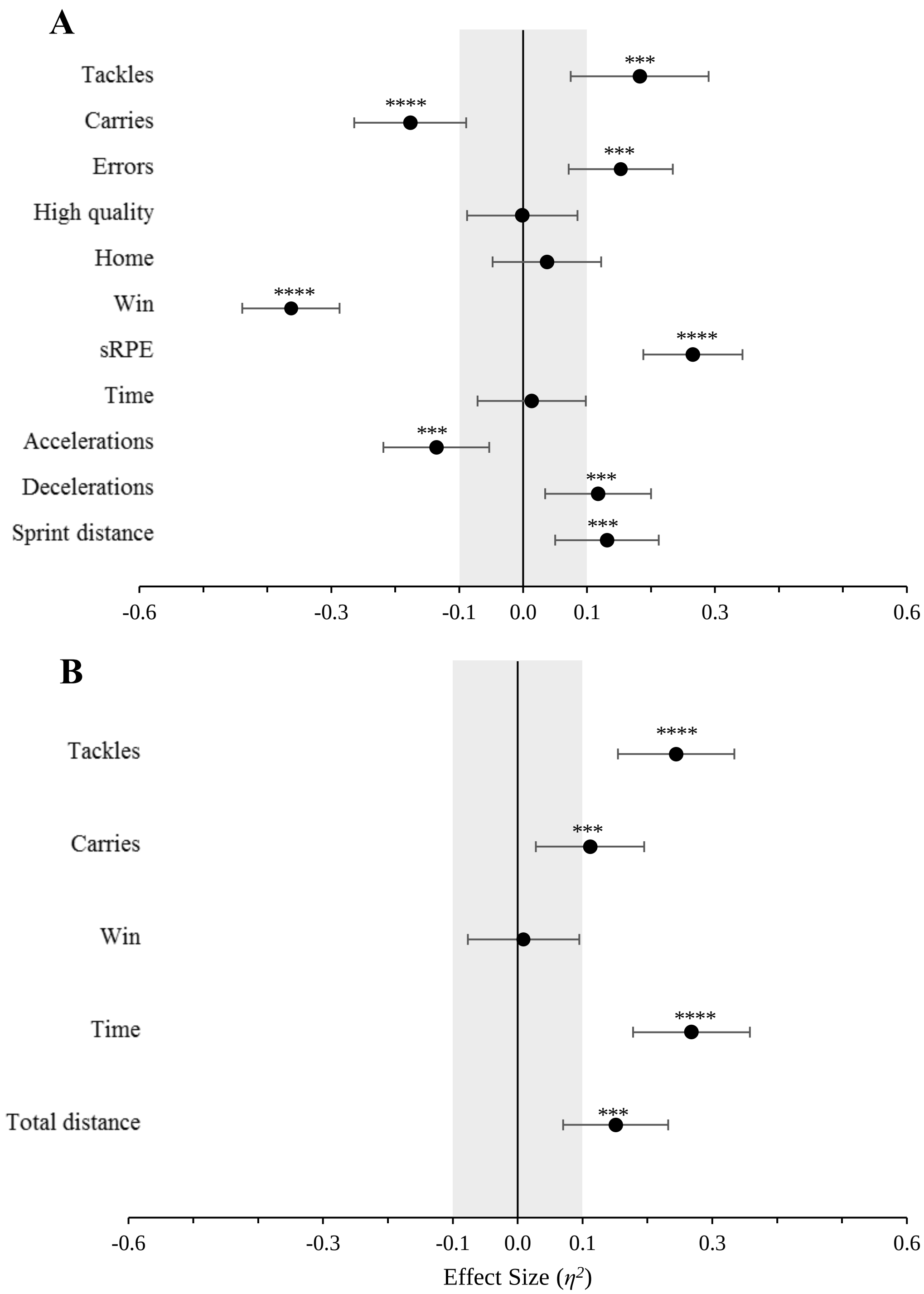

Figure 5.3. Standardised effects (effect size correlation ± 90% confidence intervals) of individual, contextual, internal and external load measures on; A=total workload (NASA-TLX), B= *s*RPE (0-10). **=possibly*, ***=likely*, ****=very likely*, *****=most likely*.

5.4 Discussion

This study is the first to describe the external loads and internal responses associated with rugby league match-play using a multidimensional rating technique (NASA-TLX), whilst attempting to describe the specific contextual, performance and movement characteristics associated with the subjective ratings of the NASA-TLX. These data provide a greater understanding of the overall external loads and internal responses of rugby league match-play, beyond reporting the external loads (GPS) and a global measure of internal load (*s*RPE).

The studied matches observed comparable average movement demands for total distance (~ 6000 m) and relative distance (~90 $m \cdot min^{-1}$) to previous research on rugby league match demands (5000-7000 m and ~ 95 $m \cdot min^{-1}$, respectively; Gabbett et al., 2012; Gabbett et al., 2013; Hausler et al., 2016; Oxendale et al., 2016; Sykes et al., 2009; Twist et al., 2014; Waldron et al., 2011). Moreover, positional differences were similar to others research (Austin & Kelly, 2013; Austin & Kelly 2014; Duffield et al., 2012; Waldron et al., 2011), whereby outside backs are on the field of play for longer (~80 min), cover more total distance (~7800 m) and more distance sprinting (~480 m) than adjustables (~70 min, 6700 m and ~240 m, respectively) and hit-up forwards (~50 min, 6100 m and ~200 m, respectively). Likewise, the average number of tackles (20.5 ± 12.5) and carries (10.7 ± 5.2) performed each match were similar to the average number of tackles (~14–25) and carries (~8–12) previously reported in Super League (Twist et al., 2012) and NRL match-play (Gabbett et al., 2012; Sirotic et al., 2009). Positional differences in the technical performance characteristics, such as number of tackles (outside backs, ~10 *cf.* hit-up forwards and adjustables, ~25) and number of passes (adjustables, ~40 *cf.* hit-up forwards, ~3 and outside backs, ~5), reflect the specific role requirements of these positions. That said, positional differences were only significantly related with temporal demand of matches. Whereby, hit-up forwards perceived temporal demand to be greater (*very likely small*) than other positional groups (outside backs and adjustables). These data likely reflect the tactical decisions of the coach, where hit-up forwards are required to 'impact' the outcome of a match within a shorter period of time (~50 min) than whole match players (~80 min; Waldron et al., 2013), culminating with an increased time pressure and perceived temporal demand.

Data from Chapter 4 suggest that altered mental loads - and associated perceived mental demand - have implications for rugby related performance (movement speeds, perceptual responses and cognitive function). Yet, the mental demand associated with rugby league competition has not been explored. In this study, no meaningful associations were documented between the reported match variables (i.e. contextual, performance and movement demands) and subjective mental demand, excluding a *likely small* increase in mental demand when players made more errors (Figure 5.2). These findings are in contrast to previous assertions of Mashiko and colleagues (2004), whereby altered mental loads and associated mental fatigue measured using profile of mood state were speculatively attributed to changes in positional specific activity profiles -despite not measuring the movement or technical demands- during rugby union match play. Whilst the number of errors made during matches have been established as important determinants of team success and match outcome (e.g. more successful teams commit fewer errors; Kempton, Sirotic & Coutts, 2017), it is unlikely that committing technical errors will exclusively increase perceived mental demand. Rather, the situation whereby 'errors' occur will likely inform a players perception of mental demand. More specifically, errors are likely to occur towards the latter stages of a match and following a peak 5 min period (Kempton et al., 2013), and so it is possible that skilled actions in association with fatigue increase the mental demands on a player. Alternatively, given that correlations cannot establish causality, it is possible that a greater mental demand in a match results in a greater number of errors. This is in agreement with studies which have shown that mentally demanding tasks before (Smith et al., 2016) and during (Greig et al., 2007) exercise can increase the number of errors during laboratory-based (concomitant exercise and computer based vigilance task; Greig et al., 2007) and field-based accuracy tasks (sport-specific skill assessment, LSPT; Smith et al., 2016). Moreover, Chapter 4 found that when mental demand was higher (i.e. a greater mental load) more errors were made during the cognitive function test (Stroop test).

Subjective ratings were similar between subscales of the NASA-TLX (62 - 78 AU), excluding ratings of performance (~40 AU). However, when these ratings were multiplied by the weighted score (i.e. weighted rating), effort, physical demand and mental demand were increased relative to performance, temporal demand and frustration. Subjective physical demand was associated with several contextual (match outcome), perceptual (*s*RPE) and external load measures (tackles, accelerations and time spent at high metabolic power) during match-play. Previously, the physical demands associated with rugby training and matches have been documented using internal (i.e. *s*RPE and *d*RPE) and external (i.e. GPS and accelerometer) load measures (McLaren et al., 2017; Waldron et al., 2013). In this study a greater number of tackles were associated with an increased subjective physical demand and overall workload (*very likely small*). This reaffirms previous work describing the importance of the tackle within actual (Twist et al., 2012) and simulated (Johnston et al., 2014; Mullen et al., 2015; Norris et al., 2016) rugby league match-play, which has shown that collisions altered players' internal loads (perception of effort), external loads (sprint performance) and fatigue response (jump performance) to exercise.

This study is the first attempt to describe the contextual, performance and movement characteristics associated with the subjective task load of elite rugby league match-play measured using the NASA task load index. Various combinations of contextual factors, technical performance and movement demands were associated with subjective overall workload (NASA-TLX) and rating of perceived exertion (*s*RPE). For example, subjective total workload was informed by the number of tackles, carries and errors made, match outcome, perception of effort, number of accelerations and decelerations and total sprint distance. *s*RPE, in contrast, was related to fewer match variables, including the number of tackles and carries made, playing time and total distance covered. Conversely, the subjective ratings of effort - derived from the NASA-TLX- were not informed by movement or physical demands but rather several contextual (quality of opposition, match outcome, number of interchanges) and perceptual (sRPE) factors. For example, when matches were won and played against better quality opposition, subjective effort was *most likely* higher. These data suggest that the global NASA-TLX and *s*RPE reflect different loads associated with rugby league match-play. It is therefore proposed that the NASA-TLX data and the associated subscales (MD, PD, TD, P, E and F) provide a greater understanding of the internal load and their association with several contextual factors, technical performance and external movement demands during rugby league competition, compared to reporting a single internal load measure (*s*RPE).

Taken together these data suggest that global load measures (sRPE and NASA-TLX) are not just a 'response' of the external loads (i.e. movement and technical demands), but are also dependant on the context of performance (e.g. opposition quality and match outcome). Therefore, coaches and practitioners should consider the contextual scenarios under which the match loads are performed, and wherever possible should incorporate a player-centred approach to load monitoring (Barrett, McLaren, Spears, Ward & Weston, 2018).

The subjective task load data, derived from the NASA-TLX, are associated with more match variables (movement, technical and contextual; Figure 5.2) than *s*RPE, and as such provides a more detailed understanding of the internal responses to competition. Indeed, previous attempts to discriminate sources of internal load using differential RPE (*d*RPE) in soccer (Barrett et al., 2018; McLaren, Graham, Spears & Weston, 2016), Australian Rules football (Weston et al., 2015) and rugby union (McLaren et al., 2017) were considered worthwhile additions to internal load monitoring procedures based on the assertion that *d*RPE will better discriminate sources of internal load than a single global measure of load (*s*RPE). Thus, the NASA-TLX is proposed as a worthwhile measure of global load during rugby league match play, however future research should determine the subjective task loads of training.

These data reaffirm that varying combinations of match characteristics likely contribute to – and- inform an individual’s internal load associated with rugby league competition (Lambert & Borresen, 2010). This information is useful given that subjective task loads (e.g. subjective mental demand) might influence performance (e.g. altered sprint performance), as demonstrated in Chapter 4 of this thesis. As training should prepare players for the specific demands of match performance (Johnston et al., 2014), it is postulated that these data could benefit coaches and practitioners when developing training practices by replicating not only the external (physical demands) and internal loads (physiological and perceptual) of rugby league matches, but also how these factors interact to inform subjective task load. Training sessions could include combinations of technical performance or movement variables to elicit specific subjective task loads. For example, based on the findings of the current study, practitioners might manipulate the subjective physical demands imposed on players by including varying number of tackles, level of competition and time spent at high metabolic power during training practices.

While these data offer insight to the contributors to total workload that might be used to design appropriate training practices, it is unknown whether these findings would elicit similar internal responses during training compared to match-play. For example, contextual factors such as match outcome and opposition quality would be difficult to replicate. Future research should consider quantifying the subjective task loads associated with current training practices.

This research has further implications for how simulation protocols are designed. Given that several contextual, performance and movement characteristics of match-play influence discrete subjective task loads and overall workload, attempts should be made to incorporate certain match characteristics to elicit similar internal as well external loads. Notably, few match specific variables are included in current simulation protocols devised to replicate the external and internal loads associated with rugby league competition (Sykes et al., 2013; Waldron et al., 2013). Since contextual factors are difficult to imitate, the performance data might be more easily introduced to protocols. For example, it is important that protocols include tackles, ball carries and opportunities for players to make errors to better replicate match-play, given their association with overall workload -and subjective mental demand (i.e. errors)- in the current study. It is speculated that including a task whereby errors are conceivable (e.g. catch and pass task) could improve the ecological validity (e.g. increased mental demand, frustration and total work load) of the current match simulation protocols.

Potential Limitations

Given the access constraints when working with elite athletes, gaining perceptual measures (subjective task load and perception of effort) ~30 min after the end of match-play - as recommended by Foster and colleagues (2001) - was logistically implausible. As such, the effect of time between matches and reporting subjective measures (*s*RPE and NASA-TLX) could be considered a limitation of these findings. However, in the current study the time between the end of matches and recording these perceptual measures were consistently taken 13-15 h post match under the same conditions, with previous research reporting a 24 h recall was a valid method of gaining *s*RPE in team sport athletes (Scantlebury, Till, Sawczuk, Phibbs & Jones, 2018; Phibbs et al., 2017), with similar ratings regardless of the time after exercise (30 min *cf*. 24 h; $r = 0.98 – 0.99$). Finally, it is noteworthy that the playing experience of players would likely effect the perceived mental demand (martin et al., 2016), despite this the inclusion of playing experience as a covariate in the model was considered outside of the scope of the study aims. That said, future research should consider the role laying experience might affect perceived subjective task load in team sports.

5.4.1 Conclusions and Practical Applications

This study suggests that the NASA-TLX is a worthwhile measure, providing increased sensitivity, when determining specific subjective loads and overall workload associated with rugby league competition, beyond the conventional method of reporting a global perceived exertion. This detailed quantification of internal loads might aid practitioners to better understand the internal load responses of their players, which could inform the prescription of recovery sessions and current training practices. In the current study, these subjective measures (NASA-TLX and *s*RPE) were conveniently reported during the recovery session following match play, and took players ~5 min to complete (pen and paper version). Taken together, this data support the use of NASA-TLX, as a practical (~5 min to report) and reliable (Chapter 3) measure of internal global load. These data highlight the complexity of rugby league competition, with several match related factors informing a player's global -and the components that make up- subjective workload. Moreover, these findings have clear implications for how training and simulation protocols are designed to better replicate the external and subjective loads associated with matches. Indeed, future research should consider these preliminary finding and use an appropriate measure of subjective task load (e.g. NASA-TLX) to describe and develop the current training practices and simulation protocols to increase their ecological validity and subsequently better prepare players for the loads associated with competition.

Chapter 6

Caffeine supplementation attenuates several negative effects of mental fatigue during simulated rugby league match-play

6.1 Introduction

Prolonged periods of demanding cognitive activity requiring sustained attention, response inhibition, working memory and error monitoring result in mental fatigue (Lorist et al., 2005). This mental fatigue is characterised by feelings of tiredness, decreased motivation and a lack of energy (Azevedo et al., 2016), which can have adverse effects on subsequent cognitive, skilled and physical performance (Boksem et al., 2005; Marcora et al., 2009; Smith et al., 2015). Indeed, when cognitive tasks requiring response inhibition are performed for 30 – 60 min, subsequent self-paced endurance (Brownsberger et al., 2013; Pageaux et al., 2014), constant-load endurance (Marcora et al., 2009; Pageaux et al., 2013) and intermittent running performance (Smith et al., 2015) are diminished. These effects are generally accompanied by an increased perception of effort during externally regulated endurance exercise (Marcora et al., 2009) or similar perception of effort with an impaired exercise performance during self-paced exercise (Smith et al., 2015).

The effects of mental fatigue on subsequent endurance or intermittent exercise are well-documented; fewer studies have explored the effects of mental fatigue on more complex exercise modes including physical, skill and cognitive demands that are characteristic of team sports. In soccer, mental fatigue induced by a 30 min Stroop task reduced distance covered in the Yo-Yo intermittent recovery test (~14.7%) and shot speed during the Loughborough soccer shooting test (~3.8%; Smith et al., 2016). Similarly, during soccer small-sided games (SSGs), mental fatigue increased the time spent at low intensities (e.g. walking and standing) and decreased defensive and offensive involvements (e.g. tackles, passes and pass accuracy; Badin et al., 2016). Notably, no studies have directly explored the effect of mental fatigue in other team sports such as rugby league. Kempton et al. (2013) demonstrated that there is a gradual decline in the number and quality of skill involvements throughout progressive quartiles of rugby league match-play, which was ascribed to a combination of mental and physical fatigue. However, mental fatigue was not measured in this investigation. In rugby union, Mashiko et al. (2004) reported that mental fatigue (measured using the Profile of Mood State) was heightened after a match; however, the implications of this mental fatigue for performance were not explored. Accordingly, investigations into the effects of mental fatigue in rugby league are warranted.

Given the potential for mental fatigue to impair sports performance, researchers have begun to explore interventions that might alleviate its effects. Caffeine intake, in doses of between 1-6 $mg \cdot kg^{-1}$, effectively enhances performance related to a variety of sports (Ganio et al., 2009; Goldstein et al., 2010), including rugby-related running (Clarke et al., 2019) and passing accuracy (Stuart et al., 2005). Some of the posited physiological mechanisms for this effect include elevated plasma β-endorphin concentrations (Laurent et al., 2000), favourable effects on metabolism (Costill et al., 1978), improved muscle ion homeostasis (Herman-Frank et al., 1999) and increased intracellular cyclic adenosine monophosphate (Magkos & Kavouras, 2005). However, perhaps caffeine's most pertinent mechanism is the blocking of adenosine receptor sites within the central nervous system (Davis et al., 2003; Graham, 2001), which induces favourable effects on perceived pain and exertion (Martin et al., 2018). Whilst the neurobiological basis for mental fatigue's effects are not certain, it has been proposed that prolonged activation of the prefrontal cortex results in an accumulation of extracellular cerebral adenosine (Martin et al., 2018). Accordingly, it is plausible that caffeine's neurobiological effects as an adenosine antagonist could ameliorate the effect of mental fatigue on sports performance. Studies that have shown that caffeine administration improves cognitive performance in the presence of mental fatigue support this notion (for a review see McLellan et al., 2016; Van Cutsem, De Pauw, Marcora, Meeusen & Roelands, 2018).

To the author's knowledge, only one study has explored the effects of caffeine on exercise performance in the presence of mental fatigue. Azevedo et al. (2016) reported that 5 $mg \cdot kg^{-1}$ caffeine improved cycling time to exhaustion in mentally fatigued individuals by ~14% compared to placebo. However, no studies have explored the efficacy of caffeine following mental fatigue for team sports, or specifically rugby, performance. Accordingly, the aims of this study were twofold: (i) to describe the effects of mental fatigue on simulated rugby league performance using a randomised version of the RLMSP-i developed in Chapters 3 and 4, and (ii) to examine the effects of caffeine supplementation on simulated rugby league performance in the presence of mental fatigue.

6.2 Methods

Participants and Design

Ten male university rugby players (league and union; age = 23 ± 4 y, body mass = 81.2 ± 6.8 kg, stature = 1.79 ± 0.06 m, predicted maximal oxygen uptake [$\dot{V}O_{2max}$] = 51.1 ± 5.5 $ml \cdot kg^{-1} \cdot min^{-1}$) completed four trials of the rugby league movement simulation protocol for interchanged players (RLMSP-i; Chapters 3 and 4) in a randomised, repeated measures, double-blind design. After baseline measurements, participants completed a control (CON), mental fatigue (MF), caffeine (MF+CAFF) and a placebo (MF+PLAC) trial of the RLMSP-i, at a similar time of day (± 2 h), with 5-8 days between trials. Participants were instructed to refrain from strenuous activity and avoid caffeine and alcohol consumption in the 24 h before each trial. A self-reported food diary for the 48 hours immediately before trial one was recorded and replicated in the 48 hours before the remaining trials to control for effects of pre-exercise dietary intake on performance (Waldron et al., 2013). Sample size estimation was calculated using the typical error of measurement of average sprint speeds (0.7 $km \cdot h^{-1}$) and smallest worthwhile change (ES = 0.56) in performance (Hopkins, 2006a); a sample of at least 10 participants was required. Participants provided written informed consent and completed a pre-test health questionnaire. Ethics approval was gained from the Faculty Research Ethics Committee (Appendix 4).

Experimental Overview

On their first visit, participants performed the multistage fitness test to estimate $\dot{V}O_{2max}$ and were habituated with all experimental procedures (for a detailed description see Chapter 3 section 2). In the four remaining visits, participants completed 30 min of either an emotionally neutral documentary (CON) or an incongruent Stroop task (MF, MF+CAFF and MF+PLAC) immediately before starting the randomised RLMSP-i (Figure 6.1). Drinks containing caffeine (MF+CAFF; 5 $mg \cdot kg^{-1}$) or placebo (MF+PLAC) were administered 60 min before starting the simulation. Throughout all protocols, movement characteristics using a global positioning system (GPS) device, heart rate (HR) and rating of perceived exertion (RPE) were recorded. Before, at half time and immediately after the protocol, Stroop test reaction time and blood lactate concentration were measured. A simple rugby passing test (RPT) was performed before, at the start and end of the half time passive recovery and immediately after the protocol. Subjective task load rating and perceived muscle soreness were reported on completion of each simulation protocol.

Procedures

Supplementation

One hour before starting the MF+CAFF and MF+PLAC trials, participants consumed a 600 ml orange flavoured sugar-free drink containing 5 $mg \cdot kg^{-1}$ caffeine (MyProtein anhydrous powder; MF+CAFF) or a placebo (nothing added; MF+PLAC), respectively. This timing (60 min) and dose of caffeine (5 ml$\cdot$kg^{-1}) was selected to coincide with peak plasma caffeine concentrations (Kalmar & Cafarelli, 2004) and subsequent ergogenic effects (Foskett, Ali & Gant, 2009; Schneiker, Bishop, Dawson & Hackett, 2006). All drinks were matched for taste and prepared by the same technician as to ensure that both the participants and experimenters were blind to the supplement. After each trial participants completed a questionnaire to determine the knowledge of the drinks content (i.e. caffeine or placebo); these answers are reported in Table 6.1. Of the 10 participants, 30% guessed correctly after the placebo drink due to "no side effects", whereas 50% guessed correctly after the caffeine drink due to greater perceived "alertness" (n=4).

Table 6.1. Descriptive data for the supplement questionnaire.

Question:	Do you know what drink you consumed?		*Result:*	
Answer:	**Yes**	**No**	**Correct**	**Incorrect**
Placebo	4	6	3	1
Caffeine	6	4	5	1

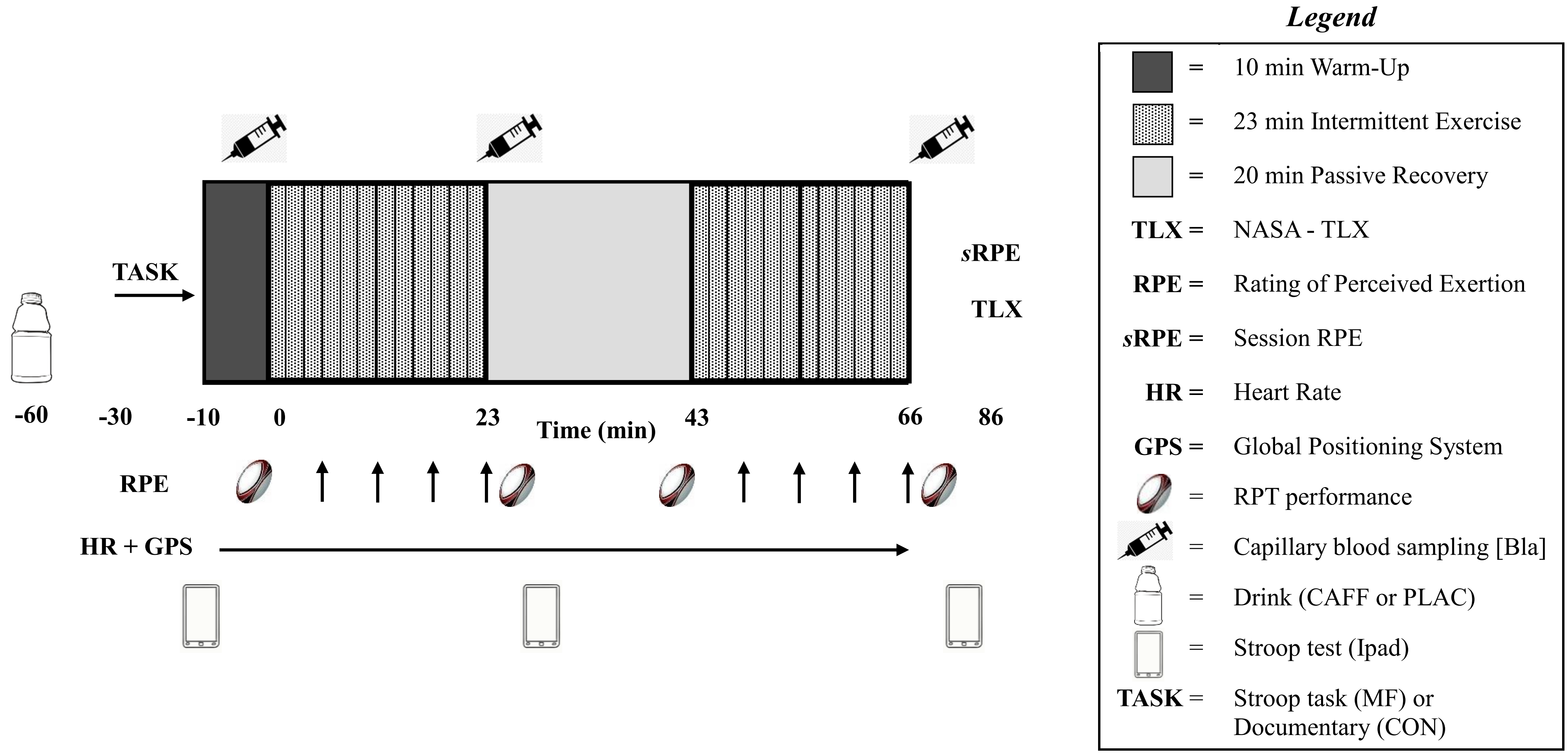

Figure 6.1. Schematic of the rugby league movement simulation protocol, including measurements. NASA-TLX = subjective task load index; RPT = rugby passing test; [Bla] = blood lactate concentration; CAFF = caffeine drink (5 mg·kg^{-1}); PLAC = placebo drink; MF = mental fatigue trial; CON = control trial.

Mental Fatigue and Control Task

Mental fatigue was induced using a 30 min modified incongruent Stroop task. Six words (red, blue, yellow, green, brown and purple) were presented in random order on two A4 sheets of paper containing 100 words printed on each sheet (10 rows x 10 columns). Participants were required to verbally respond as quickly as possible with the colour each word was printed (red, blue, yellow, green, brown and purple) and not the meaning of the word. One exemption to this rule was if the word was printed in red ink, the participant was then required to state the written word. When an incorrect response was provided the experimenter would state "no", requiring the participant to return to the start of the current line and continue as normal. The number of correct words and errors (incorrect response) were recorded by the same experimenter. In an attempt to encourage competition and maintain motivation, participants were informed of the number of words completed by others within 30 min and encouraged to better this score.

The control (CON) trial comprised 30 min watching an 'emotionally neutral' wildlife documentary (Ocean of Giants, National Geographic, 2015) on a tablet computer (Apple iPad Air 2, California, USA). A similar wildlife documentary has been adopted previously (Earth; Pageaux et al., 2013) and was considered to be emotionally neutral, requiring low cognitive demands. Both treatments (MF and CON) were performed in the same room with participants sat at a desk facing a wall, with no external audio-visual stimuli and the same experimenter present throughout. This test has been effectively used to induce mental fatigue and impair exercise performance (Smith et al., 2016; Veness et al., 2017).

Rugby League Movement Simulation Protocol

The stochastic rugby league movement simulation protocol designed for interchanged players (RLMSP-i) as described in Chapter 3 section 2 was used. Environmental temperature and humidity were recorded (THG810, Oregon Scientific Ltd., Berkshire, UK) during each

RLMSP-i, and did not differ between trials (pooled data, 16.9 ± 3.9°C and 40.8 ± 10.1%, respectively).

Movement Demands and Heart Rate

Movement and heart rate procedures are described elsewhere (Chapter 3 section 2). The satellites available and horizontal dilution of precision (HDOP) for all testing visits was 15.0 ± 0.7 (range 12 – 21) and 0.62 ± 0.06 AU (range 0.5 – 3.5), respectively.

Perceptual Measures

Immediately before and after completing the 30 min mentally fatiguing task (MF, MF+CAFF and MF+PLAC) and emotionally neutral documentary (CON), subjective ratings of mental fatigue and motivation were recorded using a VAS (Smith et al., 2016). Participants were provided with definitions of mental fatigue (i.e. increased feelings of tiredness/a lack of energy and decreased feelings of motivation and alertness) before rating their mental fatigue and motivation according to visual anchor points on the VAS scale ranging from 0 (none at all) to 100 (maximal; Smith et al, 2016). The procedures and reliability data for perceptual measures (RPE, *s*RPE and perceived muscle soreness) are described in Chapter 3 section 2.

Stroop Test

Cognitive function was assessed using an iPad based Stroop test (for a detailed description see Chapter 3 section 2). For clarity, the iPad based Stroop test and paper based 30 min Stroop task are referred in the following chapter as ‘Stroop test’ and ‘Stroop task’, respectively.

Rugby Passing Test

Passing performance was measured before, at the start and end of the half time passive recovery and immediately after the protocol, using a simple rugby passing test (RPT). This was deemed important, as other studies have reported impaired skill performance with mental fatigue (Badin et al., 2016; Smith et al., 2016b; Smith et al., 2016a), whilst Chapter 5 of this thesis demonstrated that making errors and performing skills might contribute to the overall load experienced by rugby league players. The passing protocol was a novel catch and pass test, designed to replicate several skills and attributes relating to rugby league match performance (i.e. catching, passing, decision making and agility). The test required participants to complete 12 ‘catch and passes’ (6 dominant hand and 6 non-dominant hand passes) into a target, whilst shuttle running between two poles set 10 m apart (Figure 6.2). The three passing targets were located 4 m perpendicular to the catching/passing zones (Figure 6.2). The targets were custom built wooden boards situated 0.92 m above the ground (0.85 m high, 0.91 m wide; Appendix 9). The target dimensions were calculated based upon the average height of a rugby player (1.77 m) and recommended distance the ball should be passed to a player (Worsfold & Page, 2014). All rugby balls (Rhino Hurricane XIII Rugby League Ball, Rhino Rugby Ltd., UK) were inflated prior to each testing visit according to IRB ball regulations (0.70 $kg{\cdot}cm^2$). The test began with participants passing on their ‘dominant hand’ (i.e. right hand dominant individuals would catch and pass the ball from right to left; Figure 6.2). Starting next to the pole, participants run 4 m to the ‘catch zone’ where they were passed the ball (~1.5 m pass) and received verbal instructions to pass the ball ‘Flat’ or ‘Deep’. Participants had 1 m to gather the ball in the ‘catch zone’ followed by 1 m to deliver the pass before the end of the ‘pass zone’. The end of the ‘pass zone’ were marked on each corner by a 152 cm cylindrical tackle bag (Centurion Jumbo Tackle Bag, Centurion, Dewsbury, UK), which acted as a physical barrier in an attempt to replicate the presence of a defending player. A ‘Flat’ and ‘Deep’ pass referred to the middle target (90° from the catch/pass zone) and the target backwards of the middle target (opposite from the direction of travel), respectively. After the first pass, participants would run 4 m to the opposite pole, turn 360° around the pole before running the opposite direction and completing the same process on the non-dominant hand (i.e. right hand dominant individuals would pass the ball from left to right). These 10 m shuttle runs were repeated until 12 attempts were made at passing to the target. The test comprised 6 dominant (3 x flat and 3 x deep) and 6 non-dominant (3 x flat and 3 x deep) passes, with the order of passes randomised according to a pre-determined passing sequence (Appendix 5; RPT passing sequence). The RPT performance was timed and participants were instructed to complete the test as ‘quickly as possible’ whilst attempting to hit the target. The total number of passes that went in the target were recorded, and pass·min^{-1} were later calculated. All passes were recorded using a video camera (Kodak Zi8 HD Flip Video Camera, Kodak, New York, USA) positioned 10 m behind the passing zone. Video footage was later downloaded to a PC and a ‘second marker’ assessed the number of successful passes (i.e. those that went in the target). There were no discrepancies between first and second marker. The in-house determined test–retest coefficient of variation for total number of successful passes, time to complete 12 successful passes and passes·min^{-1} during the RPT were 16.4%, 2.7% and 16.1%, respectively.

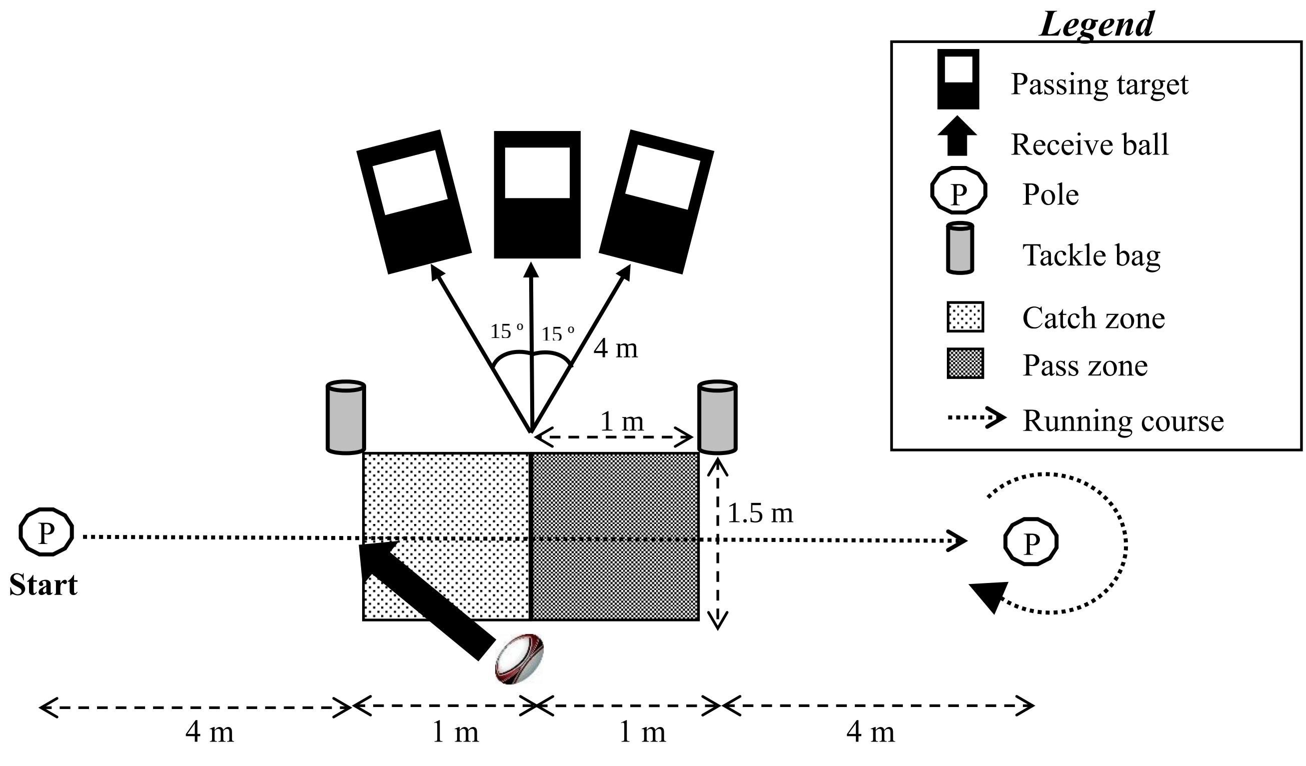

Figure 6.2. Schematic of the rugby passing test (RPT) for a right hand dominant pass.

Subjective Task Load

Subjective task load was measured using the NASA- task load index recorded ~20 min following the RLMSP-i; a detailed description of these procedures can be found in Chapter 3 section 2.

Statistical Analysis

Changes in dependent variables were analysed using magnitude-based inferences. Effect sizes were calculated as the difference between trial means divided by the pooled standard deviation and supplemented with qualitative descriptors of the mechanistic effect. The magnitude of the observed change between trials were calculated as the between-participant standard deviation (*sd*) x 0.2, 0.6 and 1.2 for a small, moderate and large effect, respectively (Hopkins et al., 2009). Previously established thresholds for the probabilities of a substantial effect based on the 90% confidence limits were utilised, they were: < 0.5% *most unlikely*, 0.5–5% *very unlikely*, 5–25% *unlikely*, 25–75% *possibly*, 75–95% *likely*, 95–99.5% *very likely*, > 99.5% *most likely* (Hopkins, 2006b). Effects with confidence limits across both a *likely small* (≥5%) positive and negative change were classified as *unclear*. All calculations were completed using a predesigned spreadsheet (Hopkins, 2006b). Data are presented as means ± SD and effect sizes (ES) ± 90% confidence intervals (CI).

6.3 Results

6.3.1 Physiological and Perceptual Measures

Mental Fatigue

Completion of the Stroop task (MF trial) resulted in greater subjective ratings of MF compared to the control trial (ES = 0.66 ± 0.45; *very likely moderate* increase) and decreased ratings of motivation (ES = -0.77 ± 0.40; *very likely moderate* decrease). Blood lactate concentrations were lower after the first (ES = -0.34 ± 0.49; *possibly small* decrease) and second bout (ES = -0.49 ± 0.50; *likely moderate* decrease) of the protocol during the MF compared to the CON trial. Unclear differences in muscle soreness, momentary RPE, and *s*RPE were observed throughout the entire protocol after the MF *cf*. CON trial (Table 6.2).

Caffeine

The MF+CAFF trial elicited greater subjective ratings of motivation immediately before the RLMSP-i compared to MF trial (ES = 0.70 ± 0.60; *likely moderate* increase). Unclear differences in muscle soreness, momentary RPE and mental fatigue were observed after the MF+CAFF compared to the MF trial (Table 6.2). Over the first and second bouts of the simulation average %HR_{max} was greater during the MF+CAFF compared to the MF trial (ES = 0.49 ± 0.47; *likely small* increase). Blood lactate concentration increased more during the MF+CAFF compared to MF trial, after the first (ES = 0.23 ± 0.39; *possibly small* increase) and second (ES = 0.97 ± 0.73; *very likely moderate* increase) bout of the simulation protocol. Session RPE was lower in the MF+CAFF compared to the MF trial (ES = -0.56 ± 0.49; *likely small* decrease).

Placebo

After consumption of the MF+PLAC drink motivation was rated higher before performing the Stroop task then when no drink was consumed (MF trial; ES = 0.55 ± 0.49; *likely small* increase); however, after the 30 min Stroop task there were unclear differences between the trials (MF *cf*. MF+PLAC; ES = 0.05 ± 0.42; *unclear*). There were unclear differences in momentary RPE, *s*RPE, muscle soreness, mental fatigue and motivation during MF+PLAC compared to MF trial. Average %HR_{max} was *likely* lower in the MF+PLAC compared to MF trial (ES = -0.46 ± 0.44; *likely small* decrease).

Table 6.2 Percentage heart rate peak, blood lactate concentration, rating of perceived exertion and session rating of perceived exertion for control, mental fatigue, caffeine and placebo trials during the whole simulation and changes in perceptual ratings of muscle soreness, mental fatigue and motivation. Mean ± SD, effect size (± 90% CI), and qualitative descriptor for comparison.

	CON	**MF**	**ES (90% CI)**	**Qualitative Descriptor**	**MF**	**CAFF**	**ES (90% CI)**	**Qualitative Descriptor**	**MF**	**PLAC**	**ES (90% CI)**	**Qualitative Descriptor**
Mental fatigue - Pre	27 ± 19	29 ± 25	0.10 (0.70)	*Unclear*	29 ± 25	24 ± 18	-0.18 (0.45)	*Unclear*	29 ± 25	23 ± 13	-0.25 (0.52)	*Unclear*
Mental fatigue - Post	36 ± 27	55 ± 20	0.66 (0.45)	*Very likely moderate ↑*	55 ± 20	53 ± 22	-0.09 (0.50)	*Unclear*	55 ± 20	63 ± 17	0.38 (0.64)	*Unclear*
Motivation - Pre	49 ± 19	42 ± 16	-0.34 (0.38)	*Possibly small ↓*	42 ± 16	52 ± 30	0.58 (0.75)	*Likely small ↑*	42 ± 16	51 ± 19	0.55 (0.49)	*Likely small ↑*
Motivation - Post	46 ± 19	30 ± 20	-0.77 (0.40)	*Very likely moderate ↓*	30 ± 20	45 ± 23	0.70 (0.60)	*Likely moderate ↑*	30 ± 20	31 ± 25	0.05 (0.42)	*Unclear*
RPE	15.1 ± 0.9	15.3 ± 1.5	0.20 (0.63)	*Unclear*	15.3 ± 1.5	15.1 ± 1.4	-0.08 (0.19)	*Unclear*	15.3 ± 1.5	14.9 ± 2.1	-0.21 (0.51)	*Unclear*
*s*RPE	6.7 ± 1.1	6.8 ± 1.1	0.13 (0.29)	*Unclear*	6.8 ± 1.1	6.1 ± 1.6	-0.56 (0.49)	*Likely small ↓*	6.8 ± 1.1	6.4 ± 1.6	-0.32 (0.67)	*Unclear*
Soreness - Pre	2.1 ± 2.5	2.2 ± 2.2	0.06 (0.42)	*Unclear*	2.2 ± 2.2	1.8 ± 1.9	-0.20 (0.36)	*Possibly small ↓*	2.2 ± 2.2	1.9 ± 1.6	-0.14 (0.54)	*Unclear*
Soreness - Post	3.0 ± 2.6	3.6 ± 2.2	0.21 (0.27)	*Possibly small ↑*	3.6 ± 2.2	3.3 ± 2.2	-0.15 (0.38)	*Unclear*	3.6 ± 2.2	3.5 ± 2.2	-0.06 (0.49)	*Unclear*
%HRmax	82.3 ± 5.6	81.3 ± 4.8	-0.17 (0.35)	*Possibly small ↓*	81.3 ± 4.8	83.9 ± 4.9	0.49 (0.47)	*Likely small ↑*	81.3 ± 4.8	78.8 ± 6.9	-0.46 (0.44)	*Likely small ↓*
[Bla] - Pre	1.6 ± 0.8	1.6 ± 1.1	0.06 (0.81)	*Unclear*	1.6 ± 1.1	1.9 ± 0.7	0.23 (0.39)	*Possibly small ↑*	1.6 ± 1.1	2.1 ± 1.8	0.40 (1.13)	*Unclear*
[Bla] - Mid	3.8 ± 2.3	2.9 ± 1.6	-0.34 (0.49)	*Possibly small ↓*	2.9 ± 1.6	4.6 ± 2.3	0.97 (0.73)	*Very likely moderate ↑*	2.9 ± 1.6	2.4 ± 1.5	-0.33 (0.53)	*Unclear*
[Bla] - Post	4.3 ± 2.8	2.8 ± 1.4	-0.49 (0.50)	*Likely moderate ↓*	2.8 ± 1.4	4.1 ± 1.7	0.83 (0.76)	*Likely moderate ↑*	2.8 ± 1.4	2.3 ± 1.0	-0.31 (0.43)	*Possibly small ↓*

$\%HR_{max}$ = percentage of heart rate maximum; RPE = rating of perceived exertion; sRPE = session rating of perceived exertion; [Bla] = blood lactate concentration; Soreness = muscle soreness (VAS).

6.3.2 Movement Demands

Mental Fatigue

The external movement demands of the CON, MF, MF+CAFF and MF+PLAC are shown in Table 6.3 and Figure 6.3. Relative distance covered at high speed (ES = -0.30 ± 0.24; *likely small* decrease), average sprint speed (ES = -0.18 ± 0.19; *possibly small* decrease), sprint to contact speed (ES = -0.20 ± 0.27; *possibly small* decrease) and time spent at high metabolic power > 20 $W{\cdot}kg^{-1}$ (ES = -0.50 ± 0.51; *likely moderate* decrease) were lower throughout the MF compared to the CON trial (Table 6.3). Average sprint speeds were lower in quartiles three and four of the first and second bouts of the protocol during MF compared to the CON trial (ES range = 0.17 – 0.30; *possibly small* decrease; Figure 6.3).

Caffeine

Relative distance covered at high speed (ES = 0.50 ± 0.53; *likely small* increase), average sprint speed (ES = 0.40 ± 0.18; *very likely small* increase), PlayerLoad™ (ES = 0.21 ± 0.22; *possibly small* increase) and time spent at high metabolic power > 20 $W{\cdot}kg^{-1}$ (ES = 0.33 ± 0.38; *possibly small* increase) were higher throughout the MF+CAFF compared to the MF trial. There were unclear differences between MF+CAFF and MF trials for total relative distance covered (ES = 0.17 ± 0.29; *unclear*), relative distance covered at low speed (ES = -0.41 ± 0.66; *unclear*) and sprint to contact speeds (ES = 0.14 ± 0.17; *unclear*). Average sprint speed was higher in the MF+CAFF compared to MF trial, during quartiles two (ES = 0.36 ± 0.22; *likely small* increase) three (ES = 0.29 ± 0.22; *possibly small* increase) and four (ES = 0.41 ± 0.30; *likely small* increase) of the first interchange bout and quartiles one (ES = 0.29 ± 0.24; *possibly small* increase), two (ES = 0.33 ± 0.26; *likely small* increase), three (ES = 0.52 ± 0.20; *very likely moderate* increase) and four (ES = 0.72 ± 0.32; v*ery likely moderate* increase) of the protocol (Figure 6.3).

Placebo

There were unclear differences in external movement demands throughout the MF+PLAC trial compared to the MF trial. Total relative distance covered (ES = 0.04 ± 0.28; *unclear*), low (ES = -0.02 ± 0.51; *unclear*) and high speed running distance (ES = 0.06 ± 0.38; *unclear*), average sprint speed (ES = 0.08 ± 0.18; *unclear*), sprint to contact speed (ES = 0.05 ± 0.23; *unclear*), average PlayerLoad™ (ES = -0.06 ± 0.25; *unclear*) and time spent at high metabolic power > 20 $W \cdot kg^{-1}$ (ES = -0.19 ± 0.44; *unclear*) were similar during MF+PLAC and MF trials.

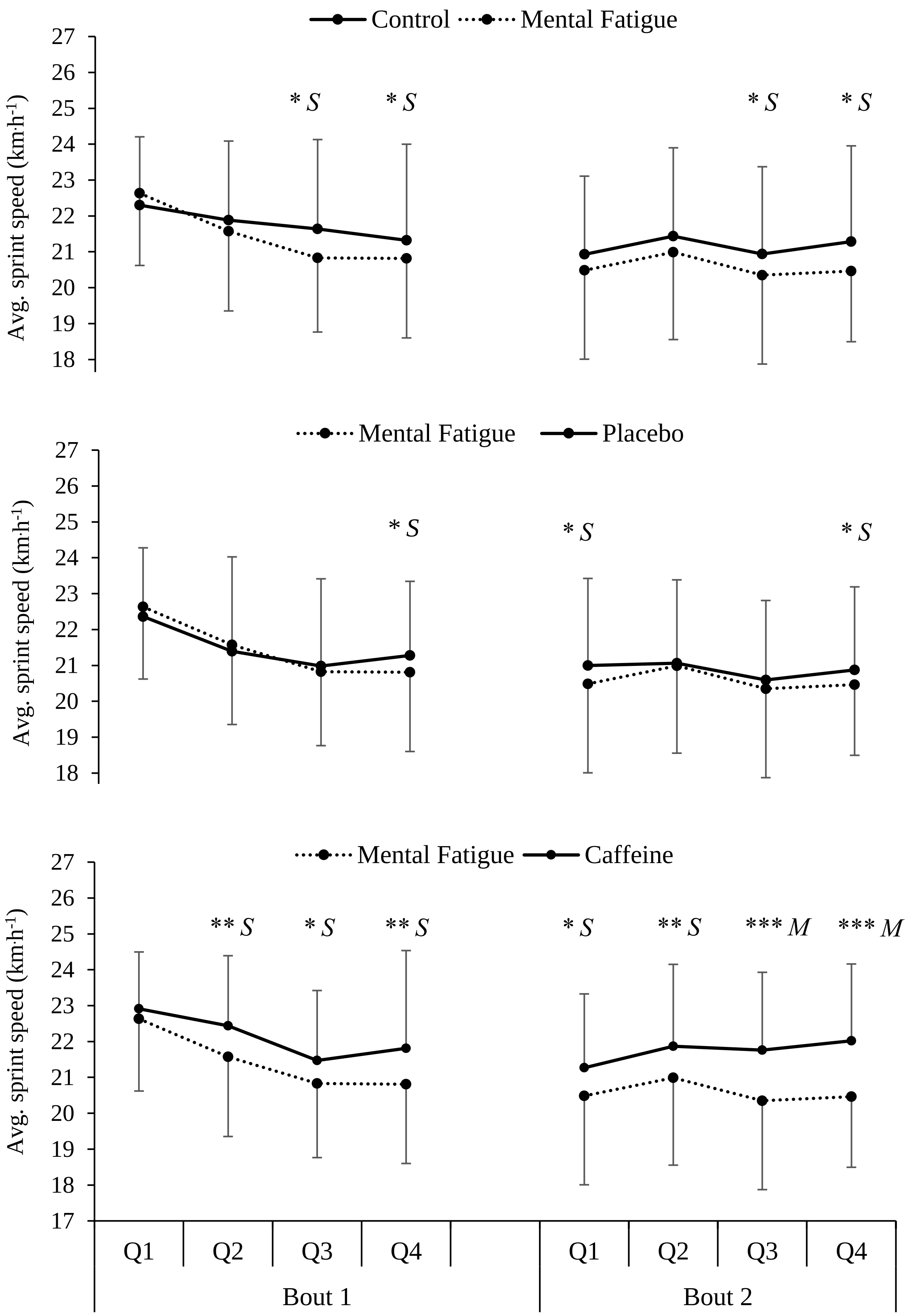

Figure 6.3. Average sprint speed during each bout quartile (Q) of the RLMSP-i.*=*possibly*, **=*likely*, ***=*very likely*, ****=*most likely*, S=*small*, M=*moderate*, L=*large*, Q = quartile.

Table 6.3 Total relative distance, low intensity activity (<14 km·h^{-1}), high intensity running (≥14 km·h^{-1}), mean sprint speed, PlayerLoad™ and time at high metabolic power >20 W·kg^{-1} for control, mental fatigue, caffeine and placebo trials during the whole simulation. Mean ± SD, effect size (± 90% CI), and qualitative descriptor for comparison.

	CON	**MF**	**ES (90% CI)**	**Qualitative Descriptor**	**MF**	**CAFF**	**ES (90% CI)**	**Qualitative Descriptor**	**MF**	**PLAC**	**ES (90% CI)**	**Qualitative Descriptor**
Total (m·min^{-1})	103.4 ± 5.0	102.8 ± 4.1	-0.11 (0.28)	*Unclear*	102.8 ± 4.1	103.6 ± 4.9	0.17 (0.29)	*Unclear*	102.8 ± 4.1	102.9 ± 4.5	0.04 (0.28)	*Unclear*
Low (m·min^{-1})	77.9 ± 4.3	79.2 ± 2.9	0.25 (0.36)	*Possibly small* ↑	79.2 ± 2.9	77.9 ± 2.0	-0.41 (0.66)	*Unclear*	79.2 ± 2.9	78.1 ± 3.7	-0.02 (0.51)	*Unclear*
High (m·min^{-1})	24.9 ± 5.4	23.2 ± 3.7	-0.30 (0.24)	*Likely small* ↓	23.2 ± 3.7	25.3 ± 4.3	0.50 (0.53)	*Likely small* ↑	23.2 ± 3.7	23.5 ± 5.3	0.06 (0.38)	*Unclear*
Sprint to contact (km·h^{-1})	12.5 ± 1.6	12.1 ± 1.8	-0.20 (0.27)	*Possibly small* ↓	12.1 ± 1.8	12.4 ± 1.8	0.14 (0.17)	*Unclear*	12.1 ± 1.8	12.2 ± 1.6	0.05 (0.23)	*Unclear*
Sprint speed (km·h^{-1})	21.5 ± 2.3	21.0 ± 2.1	-0.18 (0.19)	*Possibly small* ↓	21.0 ± 2.1	21.9 ± 2.0	0.40 (0.18)	*Very likely small* ↑	21.0 ± 2.1	21.2 ± 2.2	0.08 (0.18)	*Unclear*
PlayerLoad™ (AU)	474.9 ± 43.5	468.9 ± 59.2	-0.12 (0.32)	*Unclear*	468.9 ± 59.2	482.8 ± 57.4	0.21 (0.22)	*Possibly small* ↑	468.9 ± 59.2	465.1 ± 50.6	-0.06 (0.25)	*Unclear*
Time at HMP (s)	308.2 ± 77.8	265.5 ± 36.6	-0.50 (0.51)	*Likely moderate* ↓	265.5 ± 36.6	278.6 ± 39.3	0.33 (0.38)	*Possibly small* ↑	265.5 ± 36.6	257.9 ± 54.2	-0.19 (0.44)	*Unclear*

Total = total distance covered per minute; Low = distance covered in low intensity activity (<14 km·h^{-1}) per minute; High = distance covered in high speed running (≥ 14 km·h^{-1}) per minute; Sprint to contact = maximum speed achieved during the 8 m sprint to contact; Sprint speed = maximum speed during the 20.5 m sprint; HMP = high metabolic power (>20 W·kg^{-1}).

6.3.3 Skill Performance

Mental Fatigue

The skill performance measures of the CON, MF, MF+CAFF and MF+PLAC are shown in Table 6.4. Successful passes and the number of successful passes per minute were similar between CON and MF trials (ES range = 0.00 – 0.15; *unclear*). However, the time taken to complete the RPT was greater during the MF compared to the CON trial before the start (ES = 0.54 ± 0.63; *likely small* increase) and immediately after (ES = 0.33 ± 0.38; *possibly small* increase) the first bout of the protocol.

Caffeine

There were unclear differences in the number of passes per minute during the MF and MF+CAFF trials (ES range = -0.03 - -0.17; *unclear*). However, the MF+CAFF trial resulted in a decrease in the total number of successful passes throughout the protocol (ES = -0.27 ± 0.45; *possibly small* decrease). This coincided with decreases in the total time taken to complete the RPT during the MF+CAFF compared to the MF trial (ES = -0.65 ± 0.33; *very likely moderate* decrease).

Placebo

Unclear differences were observed for the number of successful passes made throughout the protocol (ES range = 0.05 - -0.37; *unclear*), excluding an increased number of successful passes at the end of the first bout of the protocol compared to MF (ES = 0.50 ± 0.41; *likely moderate* increase). This increase in the number of successful passes coincided with greater successful passes per minute immediately after the first bout of the protocol (ES = 0.44 ± 0.43; *likely small* increase). However, the total time to complete the RPT was greater during the MF+PLAC compared to the MF trial (ES = 0.25 ± 0.36; *possibly small* increase).

Table 6.4 Number of successful passes, time taken and successful passes per minute during the rugby passing test (RPT), before and after the first and second bout of the simulation. Mean ± SD, effect size (± 90% CI), and qualitative descriptor for comparison.

	CON	**MF**	**ES (90% CI)**	**Qualitative Descriptor**	**MF**	**CAFF**	**ES (90% CI)**	**Qualitative Descriptor**	**MF**	**PLAC**	**ES (90% CI)**	**Qualitative Descriptor**
Successful Passes (*n*)												
Pre	9.5 ± 1.8	9.8 ± 1.7	0.15 (0.49)	*Unclear*	9.8 ± 1.7	9.5 ± 2.1	-0.16 (0.74)	*Unclear*	9.8 ± 1.7	9.1 ± 1.6	-0.37 (0.64)	*Unclear*
Mid (1)	8.8 ± 2.3	8.8 ± 1.8	0.00 (0.74)	*Unclear*	8.8 ± 1.8	8.0 ± 1.9	-0.40 (0.38)	*Likely small* ↓	8.8 ± 1.8	9.8 ± 1.5	0.50 (0.41)	*Likely moderate* ↑
Mid (2)	8.6 ± 2.3	8.8 ± 3.5	0.08 (0.82)	*Unclear*	8.8 ± 3.5	8.6 ± 1.9	-0.05 (0.53)	*Unclear*	8.8 ± 3.5	9.0 ± 2.3	0.05 (0.40)	*Unclear*
Post	8.9 ± 2.0	9.2 ± 1.8	0.14 (0.80)	*Unclear*	9.2 ± 1.8	8.7 ± 1.7	-0.25 (0.69)	*Unclear*	9.2 ± 1.8	9.5 ± 0.9	0.15 (0.62)	*Unclear*
Total	35.8 ± 6.8	36.6 ± 6.2	0.11 (0.66)	*Unclear*	36.6 ± 6.2	34.8 ± 5.6	-0.27 (0.45)	*Possibly small* ↓	36.6 ± 6.2	37.4 ± 4.5	0.12 (0.33)	*Unclear*
Time (s)												
Pre	46.4 ± 3.3	48.3 ± 3.4	0.54 (0.63)	*Likely small* ↑	48.3 ± 3.4	45.7 ± 2.9	-0.70 (0.45)	*Very likely moderate* ↓	48.3 ± 3.4	47.6 ± 2.3	-0.20 (0.47)	*Unclear*
Mid (1)	48.5 ± 3.3	49.7 ± 2.8	0.33 (0.38)	*Possibly small* ↑	49.7 ± 2.8	47.2 ± 3.1	-0.85 (0.32)	*Most likely moderate* ↓	49.7 ± 2.8	50.4 ± 3.6	0.22 (0.42)	*Possibly small* ↑
Mid (2)	48.5 ± 3.5	48.4 ± 2.6	-0.02 (0.48)	*Unclear*	48.4 ± 2.6	47.0 ± 3.7	-0.50 (0.53)	*Likely small* ↓	48.4 ± 2.6	50.1 ± 3.1	0.60 (0.54)	*Likely moderate* ↑
Post	48.9 ± 3.9	48.7 ± 3.3	-0.03 (0.58)	*Unclear*	48.7 ± 3.3	47.3 ± 3.5	-0.40 (0.62)	*Unclear*	48.7 ± 3.3	50.2 ± 3.9	0.40 (0.48)	*Likely small* ↑
Total	192.3 ± 13.3	195.2 ± 11.3	0.20 (0.48)	*Unclear*	195.2 ± 11.3	187.2 ± 11.5	-0.65 (0.33)	*Very likely moderate* ↓	195.2 ± 11.3	198.3 ± 11.7	0.25 (0.36)	*Possibly small* ↑
Pass·min^{-1}												
Pre	12.4 ± 2.7	12.3 ± 2.6	-0.03 (0.49)	*Unclear*	12.3 ± 2.6	12.6 ± 3.0	0.10 (0.74)	*Unclear*	12.3 ± 2.6	11.5 ± 1.9	-0.28 (0.65)	*Unclear*
Mid (1)	10.9 ± 3.0	10.7 ± 2.2	-0.08 (0.64)	*Unclear*	10.7 ± 2.2	10.2 ± 2.6	-0.17 (0.37)	*Unclear*	10.7 ± 2.2	11.7 ± 1.9	0.44 (0.43)	*Likely small* ↑
Mid (2)	10.7 ± 2.9	10.9 ± 4.4	0.06 (0.84)	*Unclear*	10.9 ± 4.4	11.1 ± 2.8	0.05 (0.57)	*Unclear*	10.9 ± 4.4	10.8 ± 2.7	-0.02 (0.40)	*Unclear*
Post	11.0 ± 2.8	11.4 ± 2.6	0.13 (0.80)	*Unclear*	11.4 ± 2.6	11.1 ± 2.4	-0.11 (0.67)	*Unclear*	11.4 ± 2.6	11.5 ± 1.8	0.02 (0.58)	*Unclear*
Total	11.1 ± 2.5	11.4 ± 1.9	0.08 (0.53)	*Unclear*	11.4 ± 1.9	11.28 ± 2.0	-0.03 (0.52)	*Unclear*	11.4 ± 1.9	11.1 ± 1.6	-0.15 (0.32)	*Unclear*

6.3.4 Stroop Test and Task

Mental Fatigue

There were unclear differences in the number of attempts (ES range = -0.13 – 1.24; *unclear*) and time (ES range = 0.01 – 0.15; *unclear*) to complete the Stroop cognitive function test between the CON and MF trials.

Caffeine

Reaction time was quicker (ES = -0.33 ± 0.31; *likely small* decrease) and fewer attempts (ES = -0.81 ± 0.50; *very likely moderate* decrease) were made in the Stroop test after the first bout of the protocol in the MF+CAFF compared to the MF trial. The number of words read during the 30 min Stroop task were similar between MF and MF+CAFF trials (ES = -0.11 ± 0.51; *unclear*), however fewer errors were made during the MF+CAFF compared to MF trial (ES = -0.25 ± 0.36; *possibly small* decrease).

Placebo

The MF+PLAC trial resulted in greater number of attempts following the protocol compared to the MF trial (ES = 0.75 ± 0.79; *likely moderate* increase). Less time was taken to complete the Stroop test after the first bout of the protocol in the MF+PLAC compared to the MF trial (ES = -0.23 ± 0.37; *possibly small* decrease). The number of words read (ES = -0.10 ± 0.53; *unclear*) and errors made (ES = -0.11 ± 0.37; *unclear*) during the Stroop task were similar in the MF+PLAC and MF trials.

6.3.5 Subjective Task Load

Mental Fatigue

Subjective task loads were similar for CON and MF trials for ratings of MD (ES = 0.25 ± 0.46; *unclear*), PD (ES = 0.00 ± 0.56; *unclear*), P (ES = 0.00 ± 0.54; *unclear*), E (ES = 0.17 ± 0.56;

unclear) and F (ES = -0.31 ± 0.52; *unclear*). However, NASA-TLX weighted ratings (W x R) showed a decrease in MD (ES = -0.22 ± 0.28; *possibly small* decrease) and increase in PD (ES = 0.23 ± 0.33; *possibly small* increase) for the MF compared to the CON trial. The total task load was lower for MF compared to the CON trial (ES = -0.31 ± 0.46; *possibly small* decrease).

Caffeine

The MF+CAFF trial increased ratings of MD (ES = 0.34 ± 0.27; *likely small* increase), TD (ES = 0.62 ± 0.30; *very likely moderate* increase) and E (ES = 0.33 ± 0.33; *likely small* increase) compared to the MF trial. Subjective ratings for PD were lower during the MF+CAFF compared to MF trial (ES = -0.21 ± 0.29; *possibly small* decrease). The MF+CAFF trial increased weighted ratings of MD (ES = 0.46 ± 0.65; *likely small* increase) and F (ES = 0.28 ± 0.44; *possibly small* increase), with a decreased PD (ES = -0.71 ± 0.50; *very likely moderate* decrease) compared to the MF trial. However, the total task load for the RLMSP-i was similar between MF and MF+CAFF trials (ES = 0.43 ± 0.64; *unclear*).

Placebo

The MF+PLAC trial decreased ratings of PD (ES = -0.83 ± 0.81; *likely moderate* decrease) and E (ES = -0.67 ± 0.75; *likely small* decrease) compared to the MF trial. Conversely, subjective ratings of TD increased in the MF+PLAC compared to the MF trial (ES = 0.44 ± 0.56; *likely small* increase). The NASA-TLX weighted ratings were increase in MD (ES = 0.88 ± 0.80; *likely moderate* increase) and lower in PD (ES = -1.29 ± 1.02; *very likely moderate*) and E (ES = -0.54 ± 0.59; *likely small* increase) during the MF+PLAC compared to the MF trial. *Unclear* differences in total task load were observed between MF and MF+PLAC trials (ES = -0.04 ± 1.12; *unclear*).

Table 6.5 Stroop test (iPad) data during the RLMSP-i and Stroop task performance. Mean ± SD, effect size (± 90% CI), and qualitative descriptor for comparison.

	CON	MF	ES (90% CI)	Qualitative Descriptor	MF	CAFF	ES (90% CI)	Qualitative Descriptor	MF	PLAC	ES (90% CI)	Qualitative Descriptor
Stroop Test (iPad) attempts (*n*)												
Pre	11.1 ± 0.7	12.1 ± 2.6	1.24 (1.69)	*Unclear*	12.1 ± 2.6	11.8 ± 0.8	-0.11 (0.50)	*Unclear*	12.1 ± 2.6	11.7 ± 2.0	-0.14 (0.35)	*Unclear*
Mid	11.8 ± 1.3	12.2 ± 1.7	0.28 (0.99)	*Unclear*	12.2 ± 1.7	10.7 ± 0.5	-0.81 (0.50)	*Very likely moderate ↓*	12.2 ± 1.7	11.9 ± 1.8	-0.16 (0.73)	*Unclear*
Post	11.8 ± 1.4	11.6 ± 1.4	-0.13 (0.47)	*Unclear*	11.6 ± 1.4	11.9 ± 1.7	0.20 (0.74)	*Unclear*	11.6 ± 1.4	12.7 ± 1.8	0.75 (0.79)	*Likely moderate ↑*
Total	34.7 ± 2.3	35.9 ± 4.7	0.48 (0.96)	*Unclear*	35.9 ± 4.7	34.4 ± 2.4	0.29 (0.46)	*Possibly small ↓*	35.9 ± 4.7	36.3 ± 4.4	0.08 (0.50)	*Unclear*
Stroop Test (iPad) time (*s*)												
Pre	100.5 ± 22.4	103.9 ± 15.1	0.14 (0.37)	*Unclear*	103.9 ± 15.1	101.5 ± 15.8	-0.15 (0.29)	*Unclear*	103.9 ± 15.1	100.9 ± 15.5	-0.18 (0.41)	*Unclear*
Mid	97.4 ± 18.1	100.4 ± 21.9	0.15 (0.52)	*Unclear*	100.4 ± 21.9	92.5 ± 13.0	-0.33 (0.31)	*Likely small ↓*	100.4 ± 21.9	94.9 ± 15.2	-0.23 (0.37)	*Possibly small ↓*
Post	95.4 ± 16.6	95.5 ± 16.8	0.01 (0.30)	*Unclear*	95.5 ± 16.8	93.1 ± 14.9	-0.13 (0.24)	*Unclear*	95.5 ± 16.8	96.0 ± 11.6	0.02 (0.41)	*Unclear*
Total	293.3 ± 50.7	299.7 ± 50.5	0.12 (0.30)	*Unclear*	299.7 ± 50.5	287.1 ± 42.8	0.23 (0.24)	*Unclear*	299.7 ± 50.5	291.8 ± 37.6	0.14 (0.27)	*Unclear*
Stroop Task (Words)	-	-	-	-	1906 ± 486	1850 ± 479.8	-0.11 (0.51)	*Unclear*	1906.9 ± 486.9	1852.2 ± 496.3	-0.10 (0.53)	*Unclear*
Stroop Task (Errors)	-	-	-	-	18.0 ± 12.9	14.5 ± 9.1	-0.25 (0.36)	*Possibly small ↓*	18.0 ± 12.9	16.5 ± 10.1	-0.11 (0.37)	*Unclear*

Stroop Test Attempts (n) = number of attempts during the cognitive function test (Ipad); Stroop Test Time (s) = time taken to complete the cognitive function task (Ipad); Stroop Task (words) = number of words completed during the mentally fatiguing task (30 min paper based Stroop task); Stroop Task (errors) = number of errors during the mentally fatiguing task (30 min paper based Stroop task).

Table 6.6 Subjective task load data (NASA-TLX) for the RLMSP-i. Mean ± SD, effect size (± 90% CI), and qualitative descriptor for comparison.

	CON	MF	ES (90% CI)	Qualitative Descriptor	MF	CAFF	ES (90% CI)	Qualitative Descriptor	MF	PLAC	ES (90% CI)	Qualitative Descriptor
MD (R)	57.5 ± 26.9	65.0 ± 14.7	0.25 (0.46)	*Unclear*	65.0 ± 14.7	70.5 ± 17.4	0.34 (0.27)	*Likely small* ↑	65.0 ± 14.7	67.0 ± 24.7	0.12 (0.61)	*Unclear*
PD (R)	78.5 ± 9.1	78.5 ± 8.8	0.0 (0.56)	*Unclear*	78.5 ± 8.8	76.5 ± 7.8	-0.21 (0.29)	*Possibly small* ↓	78.5 ± 8.8	70.5 ± 15.9	-0.83 (0.81)	*Likely moderate* ↓
TD (R)	61.0 ± 16.1	55.5 ± 12.6	-0.31 (0.31)	*Possibly small* ↓	55.5 ± 12.6	64.0 ± 15.1	0.62 (0.30)	*Very likely moderate* ↑	55.5 ± 12.6	61.5 ± 19.6	0.44 (0.56)	*Likely small* ↑
P (R)	41.5 ± 27.1	41.5 ± 21.2	0.00 (0.54)	*Unclear*	41.5 ± 21.2	39.5 ± 24.2	-0.09 (0.53)	*Unclear*	41.5 ± 21.2	41.5 ± 15.3	0.00 (0.66)	*Unclear*
E (R)	77.0 ± 18.7	80.5 ± 6.9	0.17 (0.56)	*Unclear*	80.5 ± 6.9	83.0 ± 4.8	0.33 (0.33)	*Likely small* ↑	80.5 ± 6.9	75.5 ± 10.9	-0.67 (0.75)	*Likely small* ↓
F (R)	63.5 ± 17.5	57.5 ± 19.5	-0.31 (0.52)	*Unclear*	57.5 ± 19.5	57.0 ± (22.8)	-0.02 (0.49)	*Unclear*	57.5 ± 19.5	60.5 ± 27.2	0.14 (0.51)	*Unclear*
MD (WxR)	137.0 ± 101.9	112.0 ± 103.4	-0.22 (0.28)	*Possibly small* ↓	112.0 ± 103.4	164.0 ± 130.3	0.46 (0.65)	*Likely small* ↑	112.0 ± 103.4	211.0 ± 158.2	0.88 (0.80)	*Likely moderate* ↑
PD (WxR)	296.5 ± 108.5	323.5 ± 84.5	0.23 (0.33)	*Possibly small* ↑	323.5 ± 84.5	257.5 ± 116.3	-0.71 (0.50)	*Very likely moderate* ↓	323.5 ± 84.5	204.5 ± 132.3	-1.29 (1.02)	*Very likely moderate* ↓
TD (WxR)	84.5 ± 94.9	82.0 ± 100.1	-0.02 (0.27)	*Unclear*	82.0 ± 100.1	96.5 ± 129.3	0.13 (0.31)	*Unclear*	82.0 ± 100.1	88.0 ± 101.1	0.05 (0.64)	*Unclear*
P (WxR)	81.5 ± 64.7	102.0 ± 84.0	0.29 (0.55)	*Unclear*	102.0 ± 84.0	91.0 ± 98.9	-0.12 (0.42)	*Unclear*	102.0 ± 84.0	85.5 ± 51.2	-0.18 (0.56)	*Unclear*
E (WxR)	346.0 ± 134.2	329.5 ± 64.9	-0.11 (0.51)	*Unclear*	329.5 ± 64.9	348.5 ± 76.8	0.27 (0.69)	*Unclear*	329.5 ± 64.9	291.5 ± 118.0	-0.54 (0.59)	*Likely small* ↓
F (WxR)	126.0 ± 101.5	97.0 ± 94.7	-0.26 (0.65)	*Unclear*	97.0 ± 94.7	126.0 ± 143.9	0.28 (0.44)	*Possibly small* ↑	97.0 ± 94.7	162.0 ± 193.0	0.63 (0.88)	*Unclear*
Total	71.4 ± 5.1	69.7 ± 5.4	-0.31 (0.46)	*Possibly small* ↓	69.7 ± 5.4	72.23 ± 7.1	0.43 (0.64)	*Unclear*	69.7 ± 5.4	69.5 ± 12.4	-0.04 (1.12)	*Unclear*

MD, mental demand; PD, physical demand; TD, temporal demand; P, performance; E, effort; F, frustration; R, rating (0-100 AU); WxR, weighted rating; Total, total subjective task load index.

6.4 Discussion

This study has demonstrated that completing a mentally demanding task increases participants' subjective rating of mental fatigue (*very likely moderate*) and decreases motivation (*very likely moderate*) immediately before completing a simulation protocol, with changes in mental fatigue (pre = 29 ± 25 AU; post = 55 ± 20 AU) comparable to previous research using the same 30 min paper-based incongruent Stroop task (pre = 22 ± 11 AU; post = 58 ± 22 AU; Smith et al., 2016). Similarly, changes in motivation are consistent with a reduced intrinsic motivation towards upcoming physical tasks after similar mentally demanding tasks (Boksem & Tops, 2008; Van Cutsem et al., 2017). These data suggest that a state of mental fatigue was achieved using the 30 min incongruent Stroop task, given that perceptual responses are defined by elevated feelings of mental fatigue and reduced motivation for upcoming tasks (Van Cutsem et al., 2017).

There was no clear change in the perceived mental demand of the exercise trial with mental fatigue. However, the weighted rating for mental demand *possibly* decreased with mental fatigue, potentially owing to a greater relative weighting of the perceived physical demand of the protocol when mentally fatigued; that is, participants perceived the physical demand of exercise to be relatively more important than mental demands when mentally fatigued. An increased perceived mental demand associated with mentally demanding tasks is often reported (Mehta & Parasuraman, 2014; Smit, Eling, Hopman & Coenen, 2005). However, to the author's knowledge, this is the first study to use the NASA-TLX to establish different contributing factors to perceived load in a prolonged exercise bout after a mentally demanding task. Accordingly, it appears that mental fatigue might exert greater effects on perceived physical demands, rather than mental demands, of subsequent exercise.

An increase in the perceived physical demand of exercise is in agreement with the observation that mental fatigue increases perceived exertion during fixed-intensity exercise (Marcora et al., 2009). Whilst there was no change in RPE with mental fatigue in the present study, it is notable that several movement variables and physiological responses (heart rate and blood lactate) demonstrated *small* decreases. Thus, RPE was higher for a given load (internal and external) when mentally fatigued and could be because of an accumulation of localised cerebral adenosine and an impaired dopamine release (Martin et al., 2018). Indeed, performance of a mentally demanding task is associated with increased activation of, and therefore adenosine accumulation in, the anterior cingulate cortex, an area of the prefrontal cortex responsible for generating perception of effort (Lorist et al., 2005; Marcora et al., 2009; Martin et al., 2018). Given the inhibitory properties of adenosine (Martin et al., 2018), it is postulated that greater stimulatory input to the sensory areas of the cerebral cortex -from the motor regions of the brain- are needed to produce a given motor output (i.e. for sprinting; Marcora et al., 2009). Additionally, a greater corollary discharge is needed from the motor cortex to the anterior cingulate cortex, leading to an elevated perception of effort (Martin et al., 2018; Marcora et al., 2009).

In agreement with other investigations into endurance (Marcora et al., 2009; MacMahon et al., 2014; Pageaux et al., 2014) and team sport performance (Badin et al., 2016; Smith et al., 2015), this study shows for the first time that mental fatigue reduces physical performance in a simulated rugby league match. Specifically, impairments in sprint speed, sprint to contact speed, high-intensity running and time at high metabolic power > 20 $W \cdot kg^{-1}$ were observed after the mentally demanding task. Such impairments are possibly because of the aforementioned decreased motivation and altered RPE (relative to external and internal load) after the mental fatigue trial. According to the psychobiological model of endurance exercise, performance is largely governed by the maximum effort that someone is willing to exert (i.e.

their motivation) and their perception of exertion during exercise (Marcora, 2008). It is possible that the participants exercised to the same 'template' RPE in each trial (Tucker, 2009), but down-regulated their exercise intensity when mentally fatigued due to an elevated perceived exertion for a given internal and external load (Brownsberger et al., 2013; Pageaux et al., 2014).

Several studies have reported team-sport related measures of skill, decision making and technical performance are negatively affected after mental fatigue (Badin et al., 2016; Smith et al., 2016a; Smith et al., 2016b). In the present study, mental fatigue did not affect Stroop test performance or passing accuracy; however the time taken to complete the passing test increased before and after the first bout of the RLMSP-i. This finding is in contrast to that of Smith et al. (2016b), who reported that mental fatigue did not change the time taken to complete the Loughborough Soccer Passing Test, but did result in a greater number of passing errors (which were ascribed 'penalty times', and thus increased the performance time of the test). However, as Smith et al. (2016b) note, it has been posited that a speed-accuracy trade-off occurs during cognitive tasks in mentally fatigued individuals (Lorist et al., 2000). In this study, it appears that participants sacrificed speed to maintain rugby passing accuracy in the face of possible changes in motor skill (Duncan et al., 2015), anticipation (Smith et al., 2016a), decision making (Smith et al., 2016a) and goal-directed attentional focus (Rozand et al., 2015) associated with mental fatigue. It is also noteworthy that changes in passing time with mental fatigue were only present before and immediately after the first 23 min bout of the RLMSPi, and thus the effects of mental fatigue on skill might be transient. This is in agreement with previous research, whereby the deleterious effects of mental fatigue were diminished ~50 min after completing a cognitively demanding task (90 min AX-CPT; Smith et al., 2015).

Caffeine supplementation attenuated several adverse effects of performing a cognitively demanding task before exercise replicating the demands of rugby league match-play. This is in agreement with studies which have shown caffeine can effectively abate decrements in endurance performance (Azevedo et al., 2016) and cognitive ability (Van Cutsem et al., 2018) associated with mental fatigue. Caffeine, in the presence of mental fatigue, increased the external (high speed running, sprint speeds, PlayerLoad™ and high metabolic power > 20 $W \cdot kg^{-1}$) and internal ($\%HR_{max}$ and blood lactate) loads, with an overall reduced perception of effort (*s*RPE) and perceived physical demand; effects which were not present in the placebo trial. These findings are in agreement with previous research in team sports (Azevedo et al., 2016; Roberts et al., 2010; Wellington et al., 2017) and a study using a similar simulation of rugby league match-play, whereby average sprint speeds and high intensity running were improved, with a lowered perception of effort after participants consumed 3 $mg \cdot kg^{-1}$ caffeine (Clarke et al., 2019). These reductions in RPE are considered a consequence of caffeine binding with adenosine receptors in the brain, consequently reducing the negative effects of adenosine accumulation induced by mental fatigue and prolonged exertion (Davis et al., 2003; Fredholm, 1995). Further mechanistic studies are required to support this assertion.

A further benefit of caffeine whilst mentally fatigued was a *likely moderate* improvement in the time taken to complete the Stroop test, the number of attempts required to complete the Stroop test and the time taken to complete the passing test. However, this was accompanied by a *possible small* impairment in passing accuracy. This is in contrast to previous research whereby caffeine had unclear effects on a dynamic rugby passing task (Assi & Bottoms, 2014), and in partial agreement with the observation that caffeine can abate rugby passing performance decrements associated with sleep deprivation (Cook et al., 2011). The passing test findings in this study further supports the notion that an accuracy-speed trade off occurred; participants performed the passing test quicker (which was the key instruction of the test), after a reduction in RPE and enhanced motivation, which was marginally offset by a reduction in passing accuracy (Smith et al., 2016). However, given that changes in the number of successful passes (1.8 passes) were greater than the in-house determined typical error (TE = 1.5 passes), it is unclear if these changes are meaningful. In contrast, time to complete the passing test is the most reliable measurement from the passing test (TE = 1.3 s), and therefore the *likely* to *very likely moderate* decreases in time to complete the test are probably due to the nutritional intervention and not measurement error.

Finally, whilst it cannot be ruled out that some of the benefits associated with caffeine when mentally fatigued were due to a placebo effect (Beedie, Stuart, Coleman & Foad, 2006), the present study indicated that the physical, perceptual, technical and cognitive improvements were not present in the placebo trial. As such, it seems likely that caffeine has substantive beneficial effects.

6.4.1 Conclusions and Practical Applications

This chapter has shown that mental fatigue has adverse effects on the internal loads, external loads and skill performance during simulated rugby league match-play that appear to be centrally regulated by a decreased motivation and increased perception of effort. However, a single dose of caffeine taken 60 min before performance can attenuate several of these negative effects. Given the negative effects of performing cognitively demanding tasks on subsequent exercise simulating rugby league match-play, players should avoid such tasks before competition. Where coaches and practitioners suspect rugby players might be at risk from mental fatigue impairing components of physical and technical performance during match-play, they should consider caffeine supplementation at similar doses to those used in the current study ~60 min before kick-off. However, these findings should be cautiously extrapolated to real world scenarios given players are likely to be highly motivated before match-play, a response that might diminish the effects of caffeine on mental fatigue.

Chapter 7

Conclusions

The current thesis comprises empirical data (Chapters 3-6) collected with the intention of developing knowledge of the 'loads' associated with rugby league match-play (Chapter 5) and the potential effects of altered mental loads before (Chapter 6) and during (Chapter 4) exercise indicative of a rugby league match, using a modified simulation replicating the movement characteristics (Chapter 3). The following are the main findings from this work taken from the empirical data chapters, with pertinent practical applications (Chapter 7 section 5) and directions for future research (Chapter 7 section 6) put forward.

7.1 Mental Loads and Rugby League Performance

The specific mental loads associated with rugby league match performance are seemingly difficult to quantify. To the author's knowledge, Chapter 5 is the first study to describe the subjective task load - including perceived mental load - associated with elite rugby league competition. Interestingly, only one of the measured variables (number of errors) was significantly correlated with players' perceived mental demand, despite 'mental demand' (i.e. how much mental and perceptual activity was required: for example thinking, deciding, calculating, and remembering) providing a considerable contribution to global load during matches (~14%; Chapter 5). The lack of related variables highlights the multifactorial nature of 'mental load' and is likely a result of large individual variability, and/or that factors outside of those reported in Chapter 5 (e.g. pre-match mental state) inform rugby league players' perceived mental load. Although useful for replicating match demands (Section 7.2) and informing methods of load monitoring in rugby league (Section 7.3), these data (i.e. describing the presence and related factors of mental load) fail to describe the specific effects of 'mental load' on rugby related performance. However, empirical data from this thesis provides evidence that altering the mental loads during (Chapter 4) and before (Chapter 6) simulated rugby league match-play has direct implications for players' internal loads, external loads and skill performance that appear to be centrally regulated, in part, by an altered perception of effort. It is worth noting that the mechanism by which these altered mental loads affect perception of effort and subsequent performance is currently unknown. However, the observation in Chapter 6 that the negative effects of mental fatigue were abated with caffeine supplementation would support the notion that cerebral adenosine accumulation with mental exertion modulates the negative effects of mental fatigue (i.e. increased perceived exertion; Smith et al., 2009; Martin et al., 2018). The response to altered mental loads is seemingly determined by the source (i.e. altered vigilance or prolonged response inhibition with sustained attention) and volume (i.e. amount of thinking, deciding, calculating, and remembering) of mental load (Chapter 4 and 6). In brief, manipulating the order of activity of the RLMSP-i to be more stochastic will impose a mental load on players, potentially due to a greater external associative attentional focus (i.e. focussing attention on completing the outcome of the task rather than the bodily movements required and associated physiological responses; Wulf, 2013), which in turn can improve self-paced sprint performance when compared to the same simulation performed with a cyclic order of activity (Chapter 4). Conversely, exposing players to a prolonged and demanding mental load (incongruent Stroop task) before exercise will diminish motivation for the upcoming task with an increased perceived exertion (relative to work completed), resulting in a down-regulation of external load during subsequent self-paced tasks (e.g. maximal sprint efforts and timed passing accuracy tests; Chapter 6). Importantly, the negative effects of imposing a pre-exercise mental load (mental fatigue trial: Chapter 6) can be attenuated with nutritional intervention (5 $mg \cdot kg^{-1}$ caffeine ~60 min before exercise) as described in Chapter 6.

Taken together, these data provide evidence that altering the mental load in a controlled environment, which replicate aspects of rugby league competition, has clear implications for performance (e.g. movement and technical performance). Therefore, efforts should be made to quantify and better understand these mental loads and associated mental states of team sport players, in an attempt to optimise performance given the reported positive (e.g. increased sprint speeds; Chapter 4) and negative (e.g. decreased sprint speeds; Chapter 6) effects of altering mental loads during and before exercise, respectively.

7.2 Replicating Match Demands

The subjective task load (total NASA-TLX) of elite rugby league match-play is associated with several technical demands (tackles and carries), contextual (match outcome) and temporal factors (time played), as well as internal (*s*RPE) and external (accelerations, decelerations and sprint distance) load measures (Chapter 5). Significant contributions of mental demand (~14%), physical demand (~21%), temporal demand (~10%), performance (~13%), effort (~29%) and frustration (~13%) to a player's subjective task load of match-play are also apparent (NASA-TLX weighted rating; Chapter 5). Interestingly, several of these 'loads' are not considered in rugby league match simulation protocols (Waldron et al., 2013b). Notably, these simulations fail to consider important technical demands (e.g. ball carrying) and mental loads (e.g. mental demand, temporal demand, and frustration) imposed on players during the RLMSP-i and the effect these loads might have on performance (i.e. pertinent internal and external measures). Several efforts were made throughout this thesis to include more pertinent facets of rugby league competition, in an attempt to determine the effects of altered mental loads on performance that more closely replicate match-play in a controlled environment (Chapters 3, 4 and 6).

Not surprisingly, the number of tackles performed throughout a match are correlated with an increased subjective physical demand and global task load (NAS-TLX; Chapter 5), reaffirming that collision events are associated with greater internal loads (*s*RPE; Lovell et al., 2013). In light of this, efforts should be made to replicate the specific loads associated with these collision events when replicating match demands (e.g. simulation protocols and training), in an attempt to increase the ecological validity of current simulations and specificity of -and adaptations to- training. However, consideration should be given to the method of simulating the collision in a controlled environment (Chapter 7 section 4.1).

Data from Chapter 4 suggests that current attempts to replicate rugby league match-play might lack ecological validity (RLMSP-i; Waldron et al., 2013b), given that these simulations comprise repeated cycles of activity that are easily learnt after a relatively short habituation (~5 min). Match-play is characterised by repeated high intensity activity, occurring in a stochastic order, within a dynamic environment. Accordingly, a modified RLMSP-i is proposed in Chapters 3 and 4, comprising randomised (no repeated cycles of activity) and therefore less predictable order of activity. This, albeit small, modification to the order of activity during the RLMSP-i goes some way to increase the associated mental demand of simulated rugby league match-play (Chapter 4) that can also be used confidently to examine interventions to evoke changes in several perceptual, neuromuscular, physiological and movement load measures related to rugby activity using stochastic movements (Chapter 3).

Figure 7.1 presents the subjective task load (NASA-TLX; rating = A, weighted rating = B) taken from each empirical data Chapter (4-6). These comparative data should be interpreted with caution given the disparity in playing standards (university *cf*. professional) and modes of exercise (simulated match-play *cf*. competitive match play) between data chapters. Nevertheless, some pertinent differences in subjective mental demands, physical demands and frustration -despite similar ‘total workload’- across the progressive Chapters of this thesis are noteworthy. Firstly, the mental demand (rating 0-100; A, Figure 7.1) appears to increase from the lowest mental demand reported after the original simulation (cyclic trial, Chapter 4; ~ 40 AU) to the largest rating of mental demand after actual match-play (Chapter 5; ~ 73 AU). With gradual increases in rated mental demands during the stochastic trial (Chapter 4; ~ 47 AU) to the control (documentary; ~ 58 AU) and mental fatigue (Stroop task; ~ 65 AU) trials in Chapter 6. Similar trends are evidenced with perceived ‘frustration’ (rating and weighted rating; Figure 7.1). Whereby perceived frustration is considerably lower during Chapter 4 (cyclic and stochastic simulations) compared to Chapters 5 (match play) and 6 (control and mental fatigue trials). Notwithstanding the differences in participant characteristics (Table 7.1), these data might suggest that a progression of this thesis has increased the ‘mental demand’ and ‘frustration’ of the simulation protocol (Chapter 6), through the inclusion of stochastic order of activity, a passing accuracy test and exposing players to a prolonged mental load before exercise. Moreover, the NASA-TLX during Chapter 6 more closely replicates the perceived frustration and mental demand reported during rugby league matches (Chapter 5) compared to the original (cyclic) and modified (stochastic) RLMSP-i (Chapter 4; Figure 7.1).

Data from Chapter 5 suggests that current simulations should incorporate skilled actions (e.g. tackles and ball carries) and create situations whereby errors are conceivable, given their association with global load (NASA-TLX). However, thought should be given to how these skills are incorporated into simulation protocols and training (e.g. passing, Hendricks et al., 2015; tackling, Norris et al., 2016; Mullen et al., 2015). Indeed, based on the data from Chapter 5, skilled actions were included in the RLMSP-i, with the inclusion of a simple rugby passing task (Chapter 6). Whilst the effects of including a skilled task were not investigated, Figure 7.1 suggest that including a skilled task (control trial; Chapter 6) resulted in a greater mental demand compared to the same simulation performed without a skilled task (stochastic trial; Chapter 4). These data also support the findings from Chapter 5, whereby skilled actions (i.e. ball carries) and the number of errors (i.e. missed passes in the RPT) are associated with perceived mental demands during rugby league matches. Furthermore, data from Chapters 4 and 6 suggest that mental loads are easily manipulated (before and during exercise), with clear implications for performance. Therefore, efforts should be made to better replicate not only selected external (physical) and internal (physiological and perception of effort) loads, but also the mental loads associated with competition (Chapter 5). However, further research is needed to determine if rugby league competition can be more closely replicated by the modification of available simulation protocols to incorporate greater mental loads that are indicative of rugby league match-play (e.g. frustration), to increase the ecological validity of the protocol.

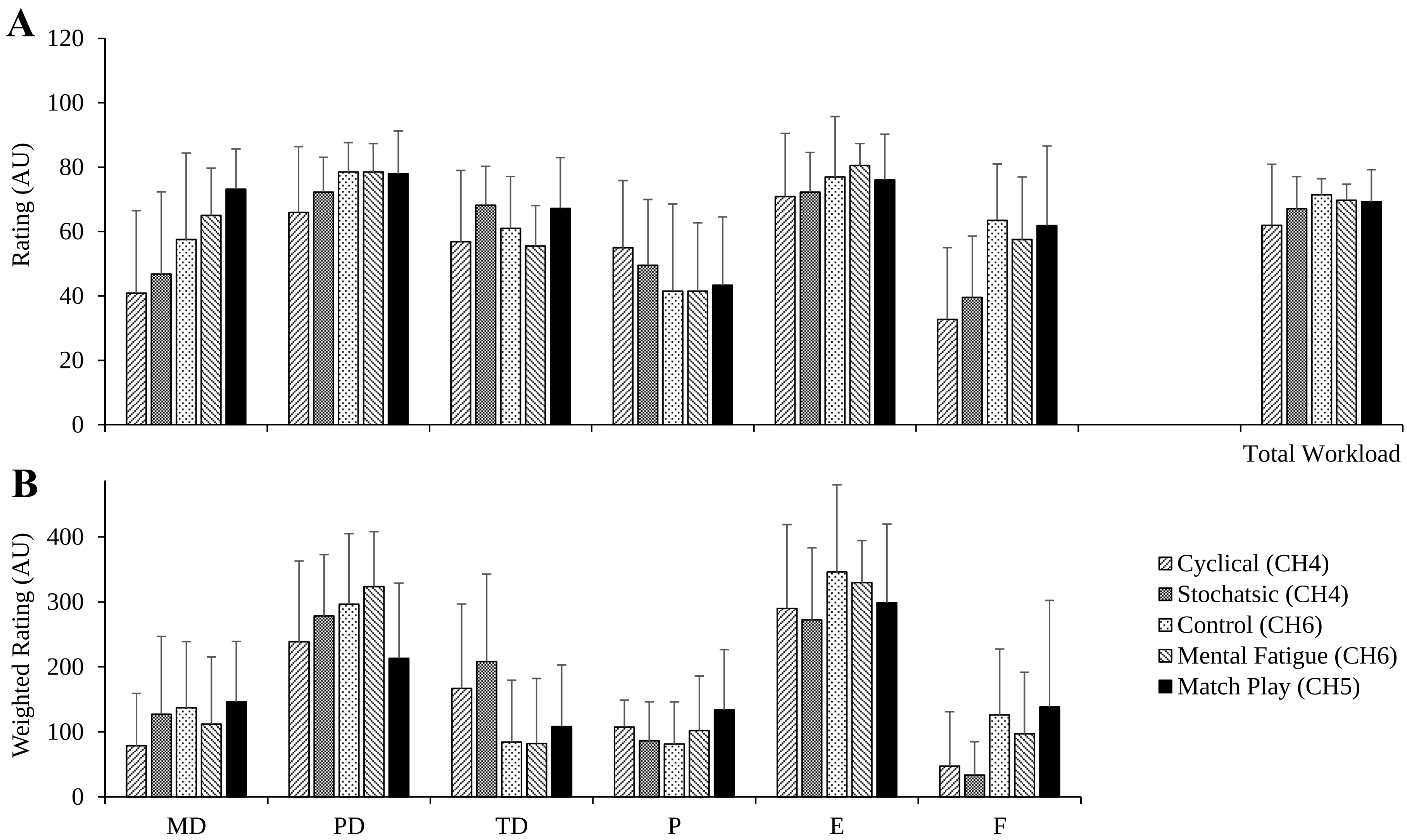

Figure 7.1. Average NASA-Task Load Index rating (**A**) and weighted rating (**B**) for the six subscales (MD, mental demand; PD, physical demand; TD, temporal demand; P, performance; E, effort; F, frustration) and total workload taken from each data Chapter of the thesis. CH, chapter; Mean ± SD.

7.3 Load Monitoring in Rugby League: An Appraisal

Data from this thesis (Chapter 4 and 6) reaffirms that altered mental loads has implications for cognitive, skilled and exercise performance (Boksem, et al., 2005; Greig et al., 2007; Marcora, et al., 2009; Smith et al., 2015). Furthermore, the inclusion of a technical demand (e.g. catch and pass; Chapter 6) might also alter the mental load associated with simulated rugby league match-play (Figure 7.1). Given the potential effects of mental and technical loads on performance, an appraisal to the current theoretical model of load monitoring in team sports is proposed below (Figure 7.2), with specific examples of rugby league competition.

In addition to incorporating the potential technical (external) and mental (internal) demands of competition when monitoring the 'loads' imposed on rugby league players, this updated model (Figure 7.2) considers the internal and external loads of competition to be multi-directional. For example, external loads (e.g. increased average sprint speeds) will inform a player's internal loads (e.g. increased $\%HR_{max}$; Chapter 4), whilst conversely internal loads (e.g. mental fatigue) can inform a player's external performance (e.g. decreased sprint speeds; Chapter 6). This is considered an appropriate appraisal of the current uni-directional internal 'demand' and external 'response' model of load monitoring (Figure 1.1). Furthermore, within this proposed model (Figure 7.2) there are several separate constructs of external (physical and technical) and internal (physiological, perceptual and mental) loads that will interact to determine performance. In support of this, Chapters 4 and 6 propose that various internal loads will interact independent of the external loads, for example altered mental load (e.g. amount of thinking and attention) will manipulate an individual's perceived exertion. The result of altered perceived exertion is apparent in subsequent self-paced efforts during the RLMSP-i (Chapter 6). Moreover, data from Chapter 5 is cognizant with previous research describing the effects of various contextual factors on players' internal (Kempton et al., 2015) and external (Kempton & Coutts, 2016) loads. This provides further evidence that coaches and practitioners should consider the loads imposed on players under the context which they are performed (e.g. quality of opposition).

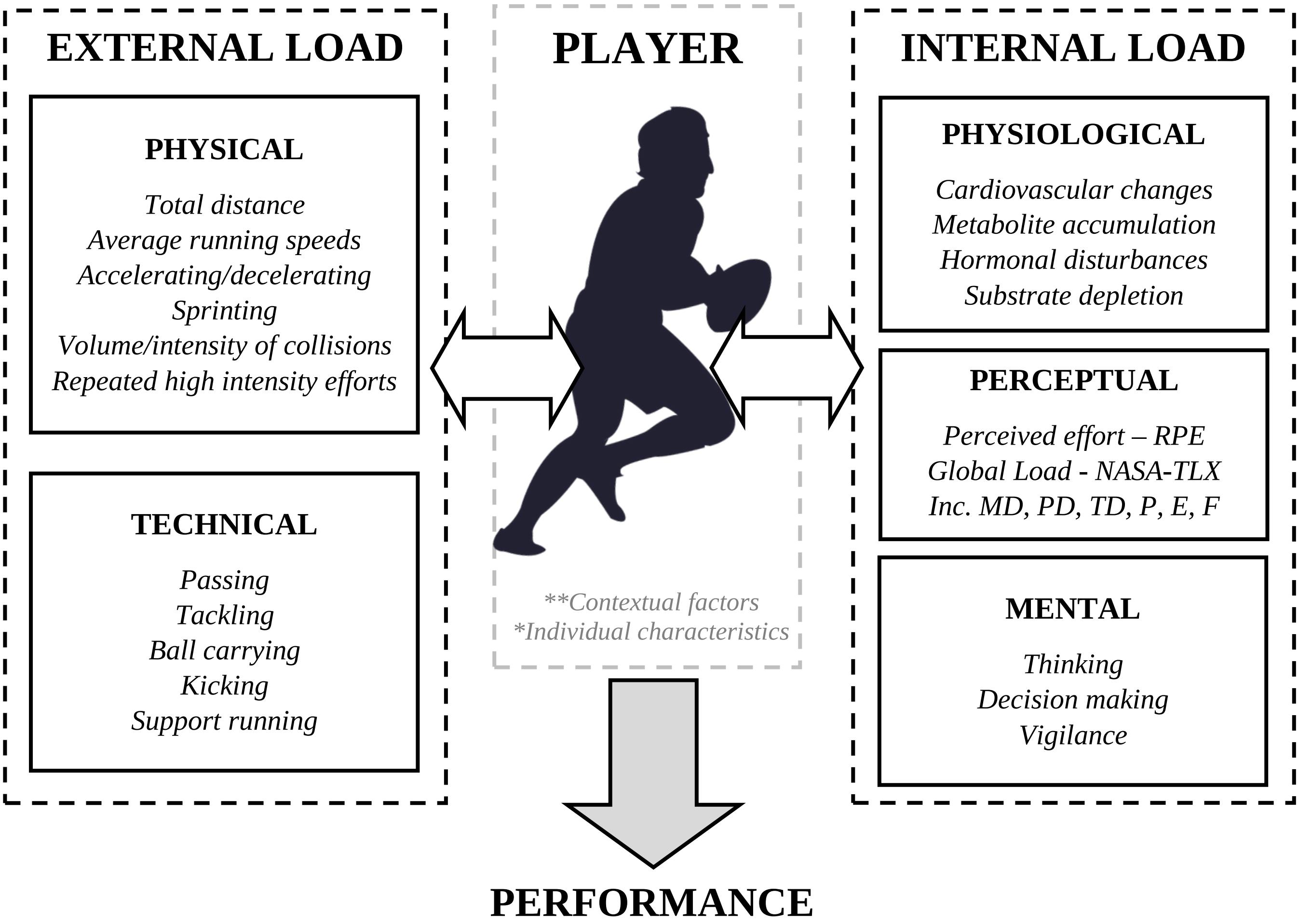

Figure 7.2 Proposed theoretical model of the external and internal loads associated with rugby league competition (*adapted from* Impellizzeri, Marcora & Coutts, 2019), modified to include technical and mental loads. **e.g. playing experience, psychological status, genetic factors, health, nutrition; **e.g. match location, match outcome, opposition quality; NASA-TLX = NASA task load index; MD = mental demand; PD = physical demand; TD = temporal demand; P =performance; E = effort; F = frustration.*

Finally, this thesis proposes that the NASA-TLX is a useful measure of 'load' for rugby league players, given that it appears to be both sensitive to changes in mental and physical loads (Chapter 4 and 6), is reliable (Chapter 3) and is associated with more variables during rugby league match-play than traditional measures of global load (*s*RPE; Chapter 5). However, the ability of the NASA-TLX to predict injury for example, like current internal perceptual measures of load (e.g. *s*RPE; Gabbett & Jenkins, 2011), is currently unknown and warrants further investigation.

7.4 Potential Limitations

7.4.1 Tackle Simulation

The current method of simulating the tackle adopted in this thesis (soft cylindrical tackle bag) poorly reflects the body-on-body collisions that players are exposed to during matches and will result in distance covered during high-speed running (>14 $km \cdot h^{-1}$) being greater than values reported in actual match-play (e.g. Waldron et al., 2011; Waldron et al., 2013). This finding was attributed to the higher speeds achieved when tackling a tackle bag (Mullen et al., 2015; Norris et al., 2016). More recently, Norris et al. (2019) proposed that body-on-body contacts during the RLMSP-i will lower total and high speed running distances to values that are closer to those reported during matches (90-100 and 15-17 $m \cdot min^{-1}$, respectively; Waldron et al., 2011). The use of a cylindrical tackle bag to replicate the collision throughout Chapters 3, 4 and 6 is therefore considered a limitation of the current thesis.

7.4.2 Participant Characteristics

Direct comparisons between data Chapters have been avoided, given the potential limitations with comparing different participants from various Chapters. However, the comparison of subjective task load data (NASA-TLX) was compared in Chapter 7 section 2, in an attempt to demonstrate the differences and similarities in actual and simulated rugby league match play. Average participant characteristics for each data Chapter are presented below in Table 7.1. Although physical qualities was not available for the professional players in Chapter 5, these players likely possess superior fitness (~55 $ml \cdot kg \cdot min^{-1}$) and skill qualities (Johnston et al., 2014; Gabbett et al., 2011; Gabbett et al., 2008) compared to amateur players (Chapters 3, 4 and 6). Furthermore, the extent to which altered mental loads (Chapter 4 and 6) might affect professional rugby league players is currently unknown.

Table 7.1 Participant characteristics for all data Chapters.

	Chapter 3	**Chapter 4**	**Chapter 5**	**Chapter 6**
Sample size (*n*)	20	11	29	10
Age (y)	21 ± 2	21 ± 2	26 ± 4	23 ± 4
Stature (m)	1.8 ± 0.1	1.8 ± 0.1	1.8 ± 0.6	1.8 ± 0.1
Body Mass (kg)	83 ± 10	81 ± 6	94 ± 10	81 ± 7
$\dot{V}O_{2max}$ ($ml \cdot kg^{-1} \cdot min^{-1}$)	49 ± 4	51 ± 4	-	51 ± 6
Playing Standard	Amateur	Amateur	Professional	Amateur

7.4.3 Differing GPS Devices

Throughout the thesis two different GPS devises were used to determine the external loads imposed on players and should be addressed as a limitation of the study. This change in devices was a consequence of the elite rugby league club (Chapter 5) having different GPS units to those available in our laboratory and used in Chapters 3, 4 and 6. The GPS units were Catapult (Chapter 3, 4 and 6; 10 Hz MinimaxX S5, Catapult Innovations, Melbourne, Australia) and Statsports (Chapter 5; 10 Hz Viper pod, STATSports Belfast, UK) devices. Therefore, data from these two devices should be compared with caution (Johnston et al., 2014). However, it is worth noting that the sample rate was the same for both units (10 Hz) and the players wore the same unit throughout all testing visits and matches to avoid any inter-unit variability. Furthermore, it is well established that the estimates derived from GPS units are not perfect (Coutts & Duffield, 2010; Highton et al., 2017a), however this limitation is not limited to this study and wherever possible the TE (Chapter 3) was used as an analytical goal to determine 'meaningful' changes in performance.

7.5 Practical Applications

7.5.1 Rugby League Training

The most notable practical application of these data is for coaches to alter, or at least consider altering the mental loads imposed on players, by avoiding repetitive and learnable training drills (e.g. repeated cycles of activity). That is, coaches could manipulate the order of activity within training practices to alter the attentional focus and perceived mental load of players, with the potential to alter subsequent self-paced efforts (e.g. maximal sprint speeds) as reported in Chapter 4. In addition, the subjective task load of match-play (Chapter 5) has various practical applications for training, given that training should prepare players for the specific demands of competition. For example, frustration significantly contributes to the global loads reported by players (Chapter 5). Therefore, coaches and practitioners might use this information to develop situations within training sessions whereby players are exposed to 'frustrating' scenarios, in an attempt to 'train' players to better cope with these loads during competition.

7.5.2 Mental Fatigue Interventions

Although performing a cognitively demanding task before simulated rugby league match-play can have adverse effects on performance (Chapter 6), a single dose of caffeine taken 60 min before performance can attenuate several of these negative effects. Given the negative effects of performing cognitively demanding tasks on subsequent exercise simulating rugby league match play, players should avoid such tasks before competition, e.g. gaming, social media, and excessive use of electronic devices. Where coaches and practitioners suspect rugby players might be at risk from mental fatigue impairing components of physical and technical performance during match play, they should consider caffeine supplementation at similar doses to those used in the current study ~60 min before kick-off.

7.6 Directions for Future Research

7.6.1 Measures of 'Load' in Rugby League

Data from this thesis purports that the NASA-TLX is a useful measure of 'load' in rugby league, given that it appears to be both sensitive to changes in mental and physical loads (Chapter 4 and 6) and is informed by more variables of rugby league match-play than traditional measures of global (internal) load (i.e. *s*RPE; Chapter 5). However, the ability of this 'load' measure (NASA-TLX) to monitor and plan training, including modelling injury risk like current methods of internal load monitoring (*s*RPE; Gabbett & Jenkins, 2011) is currently unknown. Therefore, future research should establish the efficacy of using the NASA-TLX to monitor the subjective 'loads' imposed on players during current training practices (including different modes of exercise).

7.6.2 Match Simulation

These findings have implications for how researchers can alter the mental load when simulating match performance by adopting randomised order of activity. That said, when developing a simulation of match play, the mental demand associated with the task should be considered given our findings of altered external load (sprint performance) and internal load (perception of effort) after only small modifications to the order of activities (Chapter 4). Furthermore, practitioners should consider how to better prepare players to cope with increased mental demands by training under similar conditions. Conversely, when training under 'monotonous' conditions, the perception of effort could be elevated due to a greater internal association with perception of effort; this should be considered when monitoring training load between training sessions. Finally, future research might look to incorporate sport specific performance measures that incorporate further mental demand during the RLMSP-i to enable researchers and practitioners to assess the effects of mental demands and nutritional or training interventions on measures pertinent to rugby league performance in a controlled environment (e.g. decision making task, pre-conditioning strategies).

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Appendix 1 – Ethics Approval (Chapter 3 & 4)

Faculty of Life Sciences
Research Ethics Committee

frec@chester.ac.uk

22/04/2015

Thomas Mullen
18 Barwoods Drive
Saltney
Chester

Study title: **An appraisal of the effects of randomised movement patterns during a rugby league simulation protocol (RLMSP-i)**
FREC reference: **1011-15-TM-SES**
Version number: **1**

Thank you for sending your application to the Faculty of Life Sciences Research Ethics Committee for review.

I am pleased to confirm ethical approval for the above research, provided that you comply with the conditions set out in the attached document, and adhere to the processes described in your application form and supporting documentation.

The final list of documents reviewed and approved by the Committee is as follows:

Document	Version	Date
Application Form	2	April 2015
Appendix 1 – List of References	2	April 2015
Appendix 3 – Letter(s) of invitation to participants	2	April 2015
Appendix 4 – Participant Information Sheet [PIS]	1	March 2015
Appendix 5 – Written permission from relevant personnel	1	March 2015
Appendix 6 – Risk Assessment Form	1	March 2015
Appendix 7 – Power Sample Size Calculation	1	March 2015
Appendix 8 – Testing Procedures	1	March 2015
Appendix 9 – Example Food Diary	1	April 2015
Appendix 10 – Pre-test Health Questionnaire	1	April 2015
Response to FREC request for further information or clarification		2015

Please note that this approval is given in accordance with the requirements of English law only. For research taking place wholly or partly within other jurisdictions (including Wales, Scotland and Northern Ireland), you should seek further advice from the Committee Chair / Secretary or the Research and Knowledge Transfer Office and may need additional approval from the appropriate agencies in the country (or countries) in which the research will take place.

With the Committee's best wishes for the success of this project.

Yours sincerely,

Dr. Stephen Fallows
Chair, Faculty Research Ethics Committee

Enclosures: Standard conditions of approval.

Cc. Supervisor/FREC Representative

Appendix 2 – Ethics Approval (Chapter 5)

University of Chester

Faculty of Medicine, Dentistry and Life Sciences
Research Ethics Committee

frec@chester.ac.uk

Wednesday, 3 May 2017

Thomas Mullen
18 Barwoods Drive
Saltney
Chester
CH4 8NU

Dear Thomas,

Study title: The Physical, skill and cognitive demands of professional rugby league.
FREC reference: 1278/17/TM/SES
Version number: 1

Thank you for sending your application to the Faculty of Medicine, Dentistry and Life Sciences Research Ethics Committee for review.

I am pleased to confirm ethical approval for the above research, provided that you comply with the conditions set out in the attached document, and adhere to the processes described in your application form and supporting documentation.

The final list of documents reviewed and approved by the Committee is as follows:

Document	Version	Date
Application Form	2	April 17
Appendix 1 – List of References	1	March 17
Appendix 2 – Summary CV for Lead Researcher		
Appendix 3 – Risk Assessment	1	March 17
Appendix 4 – Participant Information Sheet [PIS]	2	April 17
Appendix 5 – Letter(s) of invitation to participants	1	March 17
Appendix 6 - Consent Form		
Appendix 7 – Information sheets/letters to other relevant people		
Appendix 8 – Written permission(s) from relevant personnel (eg. to use faculties)	1	March 17
Appendix 9 – Interview schedule(s) or topic guide(s)		
Appendix 10 – Validated questionnaire(s)		
Appendix 11 – Non-validated questionnaire(s)		
Appendix 12 – Copies of advertising material(s)		
Appendix 13 – Measurement protocols		
Appendix 14 – Health screening document		
Appendix 7 – NASA-TLX Recording Sheet	1	March 17
Appendix 8 – Rating Scale Definitions	1	March 17
Response to FREC request for further information or clarification	1	April 17

Please note that this approval is given in accordance with the requirements of English law only. For research taking place wholly or partly within other jurisdictions (including Wales, Scotland and Northern Ireland), you should seek further advice from the Committee Chair / Secretary or the Research and Knowledge Transfer Office and may need additional approval from the appropriate agencies in the country (or countries) in which the research will take place.

With the Committee's best wishes for the success of this project.

Yours sincerely,

Professor Ben Green
Chair, Faculty Research Ethics Committee

Enclosures: Standard conditions of approval.

Cc. Supervisor/FREC Representative

Appendix 3 – Subjective task load (NASA-TLX) - *definitions and example rating sheet*

NASA-TLX

Rating Scale Definitions

Title	*Scale*	*Descriptions*
Mental Demand	Low/High	How much mental and perceptual activity was required (e.g. thinking, deciding, calculating, and remembering)? Was the task easy, or demanding, simple or complex, exacting or forgiving?
Physical Demand	Low/High	How much physical activity was required (e.g. pushing, pulling, running, and controlling)? Was the task easy or demanding, slow or brisk?
Temporal Demand	Low/High	How much time pressure did you feel due to the pace at which the task occurred? Was the pace slow and leisurely or rapid and frantic?
Performance	Good/Poor	How successful were you I accomplishing the goals of the task set by the experimenter? How satisfied were you with your performance?
Effort	Low/High	How hard did you have to work (mentally and physically) to accomplish your level of performance?
Frustration Level	Low/High	How insecure, discouraged, irritated, stressed and annoyed did you feel during the task, compared to being relaxed, content and complacent?

Rating Sheet

Mental Demand

Low High

Physical Demand

Low High

Temporal Demand

Low High

Performance

Good Poor

Effort

Low High

Frustration

Low High

Weighting Sheet

Effort or **Performance**	**Temporal Demand** or **Frustration**
Temporal Demand or **Effort**	**Physical Demand** or **Frustration**
Performance or **Frustration**	**Physical Demand** or **Temporal Demand**
Physical Demand or **Performance**	**Temporal Demand** or **Mental Demand**
Frustration or **Effort**	**Performance** or **Mental Demand**
Performance or **Temporal Demand**	**Mental Demand** or **Effort**
Mental Demand or **Physical Demand**	**Effort** or **Physical Demand**
Frustration or **Mental Demand**	

Appendix 4 – Ethics Approval (Chapter 6)

University of Chester

Faculty of Medicine, Dentistry and Life Sciences
Research Ethics Committee

Dear Thomas

Study title: The effects of caffeine fatigue in team sport performance.
FREC reference: 1283/17/MB/SES
Version number: 1

Thank you for sending your application to the Faculty of Medicine, Dentistry and Life Sciences Research Ethics Committee for review.

I am pleased to confirm ethical approval for the above research, provided that you comply with the conditions set out in the attached document, and adhere to the processes described in your application form and supporting documentation. However, the Committee would like to make the following recommendations:-

- Please correct the contact details for Dr Chris Haslam on the PIS and response.

Please forward an electronic copy of your amendments to frec@chester.ac.uk

The final list of documents reviewed and approved by the Committee is as follows:

Document	Version	Date
Application Form	1	March 2017
Appendix 1 – List of References	1	March 2017
Appendix 2 – Summary CV for Lead Researcher		
Appendix 3 – Risk Assessment	1	March 2017
Appendix 4 – Participant Information Sheet [PIS]	2	June 2017
Appendix 5 – Letter(s) of invitation to participants		
Appendix 6 - Consent Form	1	March 2017
Appendix 7 – Information sheets/letters to other relevant people		
Appendix 8 – Written permission(s) from relevant personnel (eg. to use faculties)		
Appendix 9 – Interview schedule(s) or topic guide(s)		
Appendix 10 – Validated questionnaire(s)		
Appendix 11 – Non-validated questionnaire(s)		
Appendix 12 – Copies of advertising material(s)		
Appendix 13 – Measurement protocols		
Appendix 14 – Health screening document	1	March 2017
Appendix 7 – RLMSP-I and rugby passing skills test layouts	1	March 2017
Appendix 8 – Diet record sheet	2	June 2017
Appendix 9 – List of foods containing caffeine	1	June 2017
Response to FREC request for further information or clarification	1	June 2017

Please note that this approval is given in accordance with the requirements of English law only. For research taking place wholly or partly within other jurisdictions (including Wales, Scotland and Northern Ireland), you should seek further advice from the Committee Chair / Secretary or the Research and Knowledge Transfer Office and may need additional approval from the appropriate agencies in the country (or countries) in which the research will take place.

With the Committee's best wishes for the success of this project.

Yours sincerely,

Professor Ben Green
Chair, Faculty Research Ethics Committee

Enclosures: Standard conditions of approval.

Cc. Supervisor/FREC Representative

Appendix 5 – Rugby Passing Test (RPT – passing sequence)

Pass No	**Sequence 1**	**Sequence 2**	**Sequence 3**
1	Deep	Flat	Deep
2	Deep	Deep	Flat
3	Deep	Deep	Flat
4	Flat	Flat	Deep
5	Flat	Flat	Deep
6	Flat	Deep	Deep
7	Deep	Flat	Deep
8	Flat	Deep	Flat
9	Flat	Deep	Flat
10	Deep	Flat	Flat
11	Flat	Deep	Flat
12	Deep	Flat	Deep

Daily Food Diary

The following food diary should be completed over the **48 hours** prior to today's session, and is designed to provide a comprehensive overview of your food and fluid intake which you will be asked to repeat on your second testing visit. In completing this food diary, you should aim to adhere to the following guidelines, using the example below as a template:

- Record all food and fluid intake during the 48 hours (even water), including the time of ingestion
- Provide information on how meals are prepared (i.e. fried, poached, grilled etc.)
- Include ingredients which are added to foods during cooking, such as olive oil, salt, butter etc.
- Provide the amount and type of food consumed in the most accurate way possible. Weighing your food is ideal, but if this isn't possible then include rough estimates on portion size (i.e. 1 cup full, teaspoon etc.)

Time	Food/Drink	Amount
9 am	Quaker porridge oats with skimmed milk	50 g, ¼ pint
	Muller fat-free Yogurt	1 average pot
10 am	Bacon sandwich (wholemeal bread) with ketchup	2 rashers, 2 slices, tablespoon

48 hours before

Time	Food/Drink	Amount

24 hours before

Time	Food/Drink	Amount

Appendix 7 – Commands throughout the modified (*stochastic*) RLMSP-i

Order of Events *(RLMSP-i-RDM)*

Quartile 1	Quartile 2	Quartile 3	Quartile 4
WALK (red)	SPRINT (blue)	JOG (red)	SPRINT (blue)
WALK (yellow)	DECELERATE	WALK (yellow)	DECELERATE
JOG (red)	SPRINT (contact)	SPRINT (blue)	SPRINT (contact)
REST	CONTACT	DECELERATE	CONTACT
WALK (yellow)	JOG (yellow)	SPRINT (contact)	REST
SPRINT (blue)	WALK (red)	CONTACT	JOG (yellow)
DECELERATE	WALK (yellow)	JOG (yellow)	WALK (red)
SPRINT (contact)	JOG (red)	WALK (red)	WALK (yellow)
CONTACT	WALK (yellow)	JOG (yellow)	SPRINT (blue)
JOG (yellow)	WALK (red)	WALK (red)	DECELERATE
WALK (red)	REST	WALK (yellow)	SPRINT (contact)
JOG (yellow)	JOG (yellow)	SPRINT (blue)	CONTACT
SPRINT (blue)	REST	DECELERATE	JOG (yellow)
DECELERATE	SPRINT (blue)	SPRINT (contact)	WALK (red)
SPRINT (contact)	DECELERATE	CONTACT	JOG (yellow)
CONTACT	SPRINT (contact)	JOG (yellow)	WALK (red)
JOG (yellow)	CONTACT	WALK (red)	REST
REST	JOG (yellow)	JOG (yellow)	JOG (yellow)
JOG (red)	WALK (red)	REST	SPRINT (blue)
JOG (yellow)	JOG (yellow)	WALK (red)	DECELERATE
REST	SPRINT (blue)	WALK (yellow)	REST
SPRINT (blue)	DECELERATE	SPRINT (blue)	SPRINT (contact)
DECELERATE	SPRINT (contact)	DECELERATE	CONTACT
SPRINT (contact)	CONTACT	SPRINT (contact)	JOG (yellow)
CONTACT	JOG (yellow)	CONTACT	WALK (red)
JOG (yellow)	WALK (red)	JOG (yellow)	JOG (yellow)
WALK (red)	WALK (yellow)	SPRINT (blue)	SPRINT (blue)
JOG (yellow)	SPRINT (blue)	DECELERATE	DECELERATE
WALK (red)	DECELERATE	REST	SPRINT (contact)
WALK (yellow)	SPRINT (contact)	SPRINT (contact)	CONTACT
WALK (red)	CONTACT	CONTACT	JOG (yellow)
JOG (yellow)	JOG (yellow)	REST	WALK (red)
SPRINT (blue)	JOG (red)	JOG (yellow)	WALK (yellow)
DECELERATE	JOG (yellow)	WALK (red)	JOG (red)
SPRINT (contact)	WALK (red)	WALK (yellow)	REST
CONTACT	REST	JOG (red)	WALK (yellow)
REST	WALK (yellow)	JOG (yellow)	REST
JOG (yellow)	REST	REST	SPRINT (blue)
SPRINT (blue)	SPRINT (blue)	SPRINT (blue)	DECELERATE
DECELERATE	DECELERATE	DECELERATE	SPRINT (contact)
REST	SPRINT (contact)	SPRINT (contact)	CONTACT
SPRINT (contact)	CONTACT	CONTACT	JOG (yellow)
CONTACT	JOG (yellow)	JOG (yellow)	JOG (red)
JOG (yellow)	REST	WALK (red)	WALK (yellow)
WALK (red)	WALK (red)	JOG (yellow)	WALK (red)
WALK (yellow)	WALK (yellow)	SPRINT (blue)	JOG (yellow)
REST	SPRINT (blue)	DECELERATE	WALK (red)
SPRINT (blue)	DECELERATE	SPRINT (contact)	WALK (yellow)
DECELERATE	REST	CONTACT	SPRINT (blue)
SPRINT (contact)	SPRINT (contact)	REST	DECELERATE
CONTACT	CONTACT	JOG (yellow)	SPRINT (contact)
JOG (yellow)	JOG (yellow)	WALK (red)	CONTACT
WALK (red)	WALK (red)	REST	JOG (yellow)
WALK (yellow)	JOG (yellow)	WALK (yellow)	REST

Time per ACTION (s)	
Sprint (blue)	3.73
Sprint (contact)	2
Decelerate	4
Jog (yellow, 20.5m)	6.83
Jog (13.5m)	4.5
Walk	11.25
Contact	8
Rest	6

Appendix 8 – OPTA operational definitions of selected performance indicators.

Action	Operational Definition	Example
Pass	A player has attempted to pass the ball with purpose to a team mate.	n/a
Tackle	A player has attempted to halt the progress or dispossess an opponent in possession of the ball.	- Chase tackle - Cover tackle - Marker tackle
Missed tackle	A tackle is deemed missed when a player has failed to affect a tackle on an opposition player when they were in a reasonable position to make a tackle.	- Bumped off - Stepped - Outpaced - Positional
Carry	A player in possession of the ball has deemed to make a carry if they have made an obvious attempt to go forward and attack the opposition with the ball in hand.	- Scoot - Kick return - Support carry - Pick and go
Metres	Metres are calculated (whilst making a carry) from the gain line.	n/a
Error	A player has made an error which leads to the opposition gaining possession of the ball, either in open play or in the form of a scrum/handover.	- Forward pass - Lost ball forced - Play the ball fumble - Knock on - Failure to find touch
Penalty	When a player or team has been deemed to be breaking the laws of the game by the referee, resulting in the opportunity to either kick for touch, tap and go or take an attempt at goal.	- Ball stealing - Interference - Dissent - Not playing the ball - Obstruction

Appendix 9 – Reactive Passing Test – Target Dimensions and Schematic.